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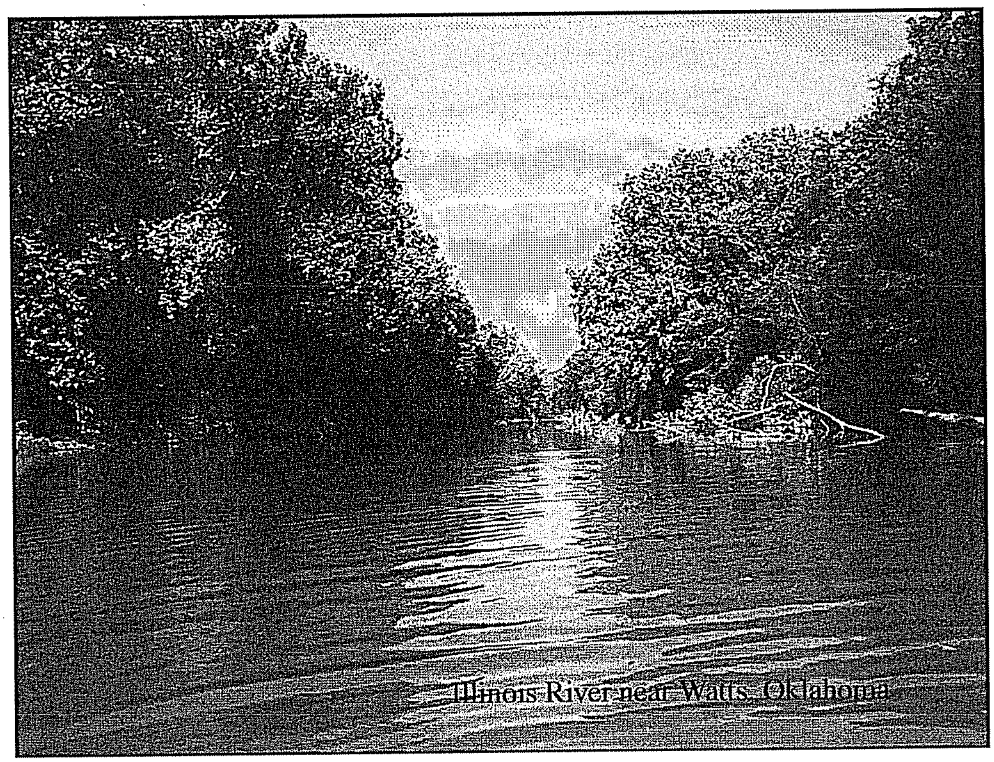
Phosphorus Concentrations, Loads, and Yields in the Illinois River Basin, Arkansas and Oklahoma, 2000–2004



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Cover Photograph Credit: Picture is Illinois River near Watts, Adair County, Oklahoma, downstream from U.S. Highway 59 bridge, taken October 11, 2002. Flow is 155 cubic feet per second. Photographer: Royce E. Johnson, U.S. Geological Survey.

Phosphorus Concentrations, Loads, and Yields in the Illinois River Basin, Arkansas and Oklahoma, 2000–2004

By Robert L. Tortorelli and Barbara E. Pickup

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Conversion Factors and Definitions

Multiply	By	To obtain
	Length	
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Mass	
pound (lb)	0.4536	kilogram (kg)
pound per day (lb/d)	0.4536	kilogram per day (kg/d)
pound per year (lb/yr)	0.4536	kilogram per year (kg/yr)
pound per year per square mile ($lb/yr/mi^2$)	0.1751	kilogram per year per square kilometer ($kg/yr/km^2$)

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L).

Estimated concentration ("E" remark code)—Positive detections below the LRL are not censored. Detected analytes with concentrations between the LT–MDL and the LRL are reported as estimated ("E" remark code). This is because a detection in this region should have a ≤1-percent probability of being a false positive (Childress and others, 1999). There are several circumstances that dictate this code, this is one of the most common.

Laboratory reporting level (LRL)—Generally equal to twice the yearly determined LT–MDL. The LRL controls false negative error. The probability of falsely reporting a non-detection for a sample that contained an analyte at a concentration equal to or greater than the LRL is predicted to be less than or equal to 1 percent. The value of the LRL will be reported with a "less than" remark code for samples in which the analyte was not detected. The National Water Quality Laboratory collects quality-control data from selected analytical methods on a continuing basis to determine long-term method detection levels (LT–MDL's) and establish laboratory reporting levels (LRL's). These values are re-evaluated annually based on the most current quality-control data and may, therefore, change (Childress and others, 1999).

Long-term method detection level (LT–MDL)—A detection level derived by determining the standard deviation of a minimum of 24 MDL spike sample measurements over an extended period of time. LT–MDL data are collected on a continuous basis to assess year-to-year variations in the LT–MDL. The LT–MDL controls false positive error. The chance of falsely reporting a concentration at or greater than the LT–MDL for a sample that did not contain the analyte is predicted to be less than or equal to 1 percent (Childress and others, 1999).

Method detection limit (MDL)—Minimum concentration of a substance that can be measured and reported with 99-percent confidence that the analyte concentration is greater than zero. It is determined from the analysis of a sample in a given matrix containing the analyte (U.S. Environmental Protection Agency, 1997). At the MDL concentration, the risk of a false positive is predicted to be less than or equal to 1 percent (Childress and others, 1999).

Minimum reporting level (MRL)—Smallest measured concentration of a constituent that may be reliably reported by using a given analytical method (Timme, 1995).

Phosphorus Concentrations, Loads, and Yields in the Illinois River Basin, Arkansas and Oklahoma, 2000–2004

By Robert L. Tortorelli and Barbara E. Pickup

Abstract

The Illinois River and tributaries, Flint Creek and Baron Fork, are designated scenic rivers in Oklahoma. Recent phosphorus levels in streams in the basin have resulted in the growth of excess algae, which have limited the aesthetic benefits of water bodies in the basin, especially the Illinois River and Lake Tenkiller. The Oklahoma Water Resources Board has established a standard for total phosphorus not to exceed the 30-day geometric mean concentration of 0.037 milligram per liter in Oklahoma Scenic Rivers. The U.S. Geological Survey, in cooperation with the Oklahoma Water Resources Board, conducted an investigation to summarize phosphorus concentrations and provide estimates of phosphorus loads, yields, and flow-weighted concentrations in the Illinois River and tributaries from January 2000 through December 2004. Data from water-quality samples collected from 2000 to 2004 were used to summarize phosphorus concentrations and estimate phosphorus loads, yields, and mean flow-weighted concentrations in the Illinois River basin for three 3-year periods—2000–2002, 2001–2003, and 2002–2004, to update a previous report that used data from water-quality samples from 1997 to 2001. This report provides information needed to advance knowledge of the regional hydrologic system and understanding of hydrologic processes, and provides hydrologic data and results useful to multiple parties for interstate compacts.

Phosphorus concentrations in the Illinois River basin were significantly greater in runoff samples than in base-flow samples. Phosphorus concentrations generally decreased with increasing base flow, from dilution, and decreased in the downstream direction in the Illinois River from the Watts to Tahlequah stations. Phosphorus concentrations generally increased with runoff, possibly because of phosphorus resuspension, stream bank erosion, and the addition of phosphorus from nonpoint sources.

Estimated mean annual phosphorus loads were greater at the Illinois River stations than at Flint Creek and Baron Fork. Annual total loads in the Illinois River from Watts to Tahlequah, increased slightly for the period 2000–2002 and decreased slightly for the periods 2001–2003 and 2002–2004. Estimated mean annual base-flow loads at stations on the Illinois River were about 11 to 20 times greater than base-flow loads at the station on Baron Fork and 4 to 10 times greater than base-flow loads at the station on Flint Creek. Estimated mean annual runoff loads ranged from 68 to 96 percent of the estimated mean annual total phosphorus loads from 2000–2004. Estimated mean seasonal base-flow loads were generally greatest in spring (March through May) and were least in fall (September through November). Estimated mean seasonal runoff loads generally were greatest in summer (June through August) for the period 2000–2002, but were greatest in winter (December through February) for the period 2001–2003, and greatest in spring for the period 2002–2004.

Estimated mean total yields of phosphorus ranged from 192 to 811 pounds per year per square mile, with greatest yields being reported for Illinois River near Watts (576 to 811 pounds per year per square mile), and the least yields being reported for Baron Fork at Eldon for the periods 2000–2002 and 2001–2003 (501 and 192 pounds per year per square mile) and for Illinois River near Tahlequah for the period 2002–2004 (370 pounds per year per square mile).

Estimated mean flow-weighted concentrations were more than 10 times greater than the median (0.022 milligram per liter) and were consistently greater than the 75th percentile of flow-weighted phosphorus concentrations in samples collected at relatively undeveloped basins of the United States (0.037 milligram per liter). In addition, flow-weighted phosphorus concentrations in 2000–2002 at all Illinois River stations and at Flint Creek near Kansas were equal to or greater than the 75th percentile of all National Water-Quality Assessment Program stations in the United States (0.29 milligram per liter).

The estimated mean annual phosphorus load entering Lake Tenkiller ranged from about 391,000 pounds per year to 712,000 pounds per year, and from about 83 to 90 percent of the load was transported to the lake by runoff.

Introduction

The Oklahoma Scenic Rivers Act of 1970 designated the Illinois River, and two tributaries, Flint Creek and Baron Fork (formerly named Barren Fork), in northeastern Oklahoma (fig. 1) as a *Scenic River* to protect water quality and preserve fish, wildlife, and outdoor recreational values for the benefit of the people of Oklahoma and visitors to the state (Oklahoma

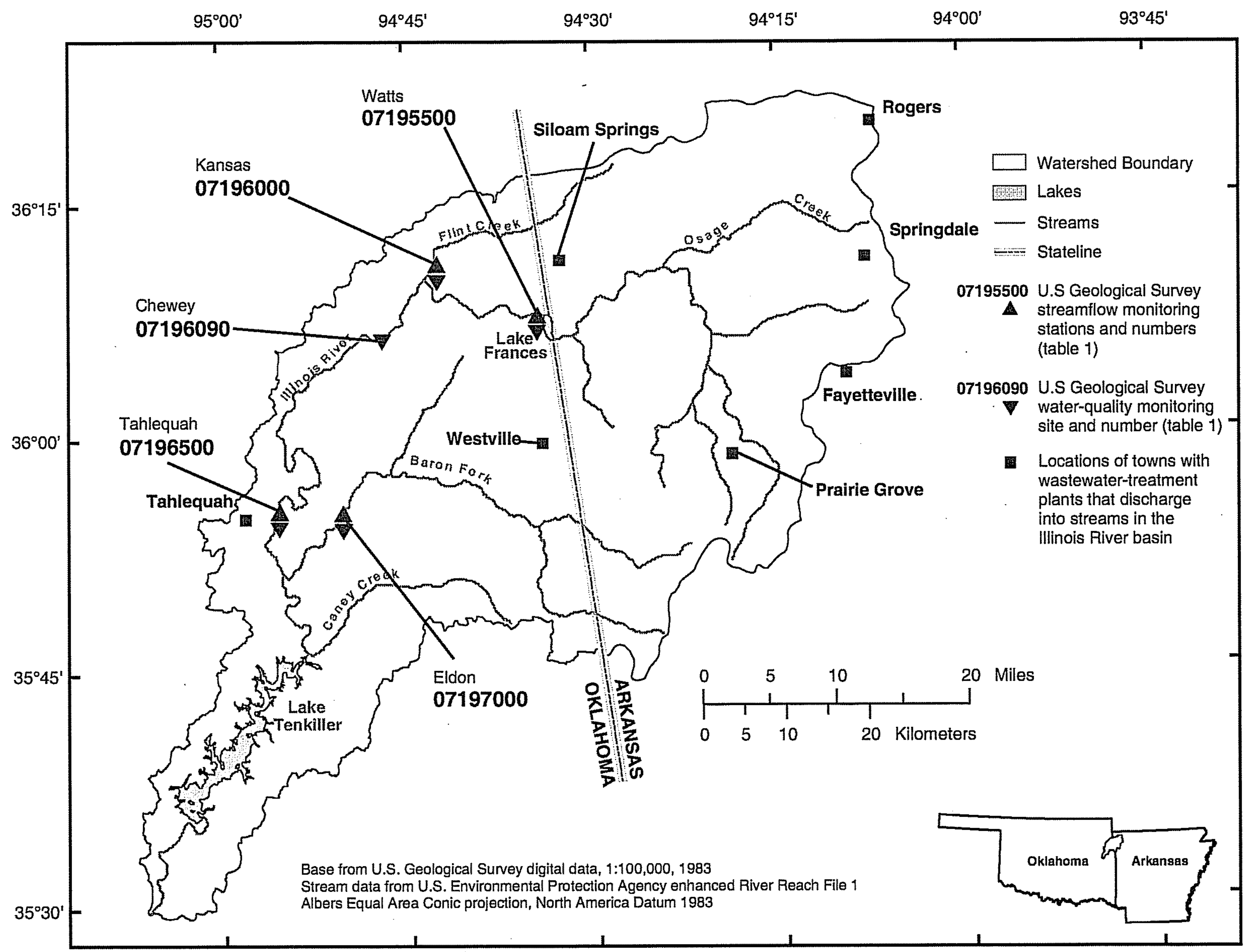

Figure 1. The Illinois River basin, Arkansas and Oklahoma, with locations of selected streamflow and water-quality stations in the basin and of towns with wastewater-treatment plants that discharge into streams in the basin (Modified from Pickup and others, 2003).

Legislature, 1970). The Oklahoma Scenic Rivers Commission was created on May 3, 1977, to enforce the stipulations of this Act (Oklahoma Legislature, 1977).

Streams in the Illinois River basin are used for primary body contact recreation (in which there is a possibility of human ingestion of water) and fisheries. Water from these streams also is used for public and private water supply and non-irrigation agriculture (Oklahoma Water Resources Board, 2000). About 400,000 tourists spend an estimated $12 million per year in the basin (Ed Fite, Oklahoma Scenic Rivers Commission, written commun., 2006). The Illinois River flows into Tenkiller Ferry Lake (referred to as Lake Tenkiller). An estimated $16.5 million is generated annually by about 1,500,000 visitors per year to the area around this lake (John Marnell, U.S. Army Corps of Engineers, written commun., 2001).

Phosphorus enters streams in discharges from wastewater-treatment plants (point-source components) and in agricultural and urban runoff (nonpoint-source components) (Oklahoma Water Resources Board, 2002a). Streams in the Illinois River basin are susceptible from both point and nonpoint sources. Elevated phosphorus concentrations promote algae growth in streams (Sharpley, 1995), and accelerate eutrophication of lakes (Daniel and others, 1998). Phosphorus levels in streams in the basin have resulted in the growth of excess algae, which have degraded the aesthetic benefits of water bodies in the basin, especially in the Illinois River and Lake Tenkiller (Oklahoma Water Resources Board, 2002b). The recreation-based economy of the area relies on maintenance of aesthetically pleasing water quality in the Illinois River basin.

The 1998 Federal Clean Water Action Plan directs the states, in conjunction with the U.S. Environmental Protection Agency, to develop numeric criteria for nutrients, including phosphorus, (U.S. Environmental Protection Agency, 1998). Oklahoma Water Resources Board has established a standard for total phosphorus concentration not to exceed 0.037 milligram per liter (mg/L) (30-day geometric mean concentration) in Oklahoma Scenic Rivers. The standard was approved by the U.S. Environmental Protection Agency in December 2003 and will be fully implemented by 2012 (Oklahoma Water Resources Board, 2004). The standard is based on the 75th percentile of flow-weighted total phosphorus concentrations from streams draining 85 relatively undeveloped basins from across the United States (referred to as relatively undeveloped basins of the United States) selected from three programs of the U.S. Geological Survey (USGS)—the Hydrologic Benchmark Network, the National Water-Quality Assessment program, and the USGS Research Program (Clark and others, 2000). Total phosphorus (referred to as phosphorus) is the concentration of dissolved phosphorus and particulate phosphorus in the sample.

The Hydrologic Benchmark Network program, initiated by the USGS in 1958, was established to track water-quality trends in streams draining basins free from anthropogenic influence and to study cause and effect relation between various physiologic, meteorologic, and hydrologic variables (Cobb and Biesecker, 1971). The Hydrologic Benchmark Network is primarily composed of relatively undeveloped basins encompassing a wide variety of natural environments nationwide (Mast and Turk, 1999).

The National Water-Quality Assessment program, initiated by the USGS in 1991, is a primary source for long-term, nationwide information on the quality of streams, ground water, and aquatic ecosystems. The information gathered through the program supports national, regional, state, and local decision making and policy formation for water-quality management (Gilliom and others, 2001). Long-term goals of the program are to describe the status and trends in the quality of the Nation's surface- and ground-water resources and determine the natural and anthropogenic factors affecting water quality (Gilliom and others, 1995).

The USGS Research Program provided research data for the assessment in Clark and others (2000) from 20 USGS research basins. These were small basins, ranging in size from about 0.04 to 8.5 square miles, that were located predominately in the Appalachian and Rocky Mountains (Clark and others, 2000).

Historical water-quality data collection in the Illinois River basin has been biased towards sampling during base-flow (non-runoff) conditions. Because of insufficient historic sampling during runoff events, calculations using historic data may have underestimated true phosphorus concentrations, loads, and yields. In July 1999, the USGS, in cooperation with the Oklahoma Scenic Rivers Commission and the Oklahoma Water Resources Board, supplemented fixed period, bimonthly water-quality sampling with six runoff-event samplings per year to better determine water quality over the range of streamflows in the basin. Pickup and others (2003) described phosphorus concentrations, loads and yields for the period of 1997–2001. Water-quality samples collected during 1997–1999 had relatively few runoff-event samples. Increases and shifts in seasonal trends of estimated annual loads and estimated seasonal loads and yields may have been partly attributable to the beginning of runoff-event sampling in the basin in July 1999. The period 2000–2004 encompasses a period where the runoff-event sampling protocol was in effect during the entire period. The U.S. Geological Survey, in cooperation with the Oklahoma Water Resources Board, conducted an investigation to summarize phosphorus concentrations and provide estimates of phosphorus loads, yields, and flow-weighted concentrations in the Illinois River and tributaries from January 2000 through December 2004.

Purpose and Scope

The purpose of this report is to summarize phosphorus concentrations and provide estimates of phosphorus loads, yields, and flow-weighted concentrations in the Illinois River and tributaries, Flint Creek and Baron Fork, from January 2000 through December 2004 and for three 3-year periods—2000–2002, 2001–2003, and 2002–2004. This report updates the work of Pickup and others (2003), which used water-quality and streamflow data from 1997 to 2001, and comprises a preliminary analysis of data collected for a multi-year monitoring program.

Phosphorus concentrations are compared among stations in the Illinois River basin, and to those measured at relatively undeveloped basins of the United States. Phosphorus loads are computed using S-LOADEST, a program to compute mean constituent loads in rivers using the rating-curve method (Dave Lorenz, USGS, written commun., 2006). S-LOADEST, based on LOADEST, uses instantaneous phosphorus concentrations and daily mean streamflows to estimate annual and seasonal (spring, summer, fall, and winter) average phosphorus loads for the study period (Crawford, 1999; Runkel and others, 2004). The report provides information needed to advance knowledge of the regional hydrologic system and understanding of hydrologic processes, and provides hydrologic data and results useful to multiple parties for interstate compacts.

Study Area Description

The Illinois River basin is about equally divided between northeastern Oklahoma and northwestern Arkansas (fig. 1). The basin is in the southwestern part of the Ozark Plateaus physiographic province (Fenneman, 1938), and is underlain by the cherty limestone of the Springfield Plateau aquifer (Adamski and others, 1995; Renken, 1998).

The basin is dominated by about equal proportions of agricultural (pasture and cropland) and forest land uses and is interspersed with minor amounts of commercial and residential land uses (fig. 2). Livestock production on pasture is the primary form of agriculture in the basin; about 48 percent of agricultural land use is pasture for cattle and horses. Numerous large-scale poultry and swine production facilities are in the basin and poultry and swine manures are used to fertilize pastures (Sims and Wolf, 1994). Approximately 226 million laying hens, broilers, or turkeys; 96,000 hogs; and 12,000 dairy cattle and 200,000 unconfined cattle are raised in the basin, mostly in the upstream part of the basin in Arkansas (Oklahoma Conservation Commission, 2000).

There also are several municipal wastewater-treatment plants that discharge phosphorus containing wastewater to the Illinois River and tributaries (Oklahoma Water Resources Board, 2002a; fig. 1). The basin is the site of one of the fastest-growing Metropolitan Statistical Areas in the United States (Fayetteville-Springdale-Rogers, Arkansas).

Streams in the Illinois River basin are exposed to potentially large concentrations of phosphorus from point sources (such as wastewater-treatment plants) and nonpoint sources (such as runoff from fertilized pastures). Phosphorus concentrations in Ozark streams are typically greater in streams draining agricultural lands than in those draining forested lands (Petersen and others, 1998; 1999) because runoff from pastures fertilized with animal manure are probably substantial sources of phosphorus to the rivers in this basin (Arkansas Department of Environmental Quality, 2000). Streams receiving municipal wastewater from treatment plants can have phosphorus concentrations substantially greater than those in streams draining agricultural areas (Petersen and others; 1998, 1999). The Illinois River and Flint Creek (fig. 1) receive discharges from wastewater-treatment plants, whereas, Baron Fork does not.

Streamflow in the Illinois River Basin

Streamflow in the Illinois River basin was highly variable and generally increased with basin drainage area (table 1, fig. 3). The maximum daily mean streamflow during the study period occurred in April 2004 for Illinois River near Watts and June 2000 for the rest of the stations, and the minimum daily mean streamflow during the study period occurred in August 2003 at all stations (table 1, fig. 3). Greatest mean monthly streamflows occurred from February through June and least mean monthly streamflows occurred from July through October at all stations (Blazs and others, 2001–2006). Continuous streamflow was not measured at the Illinois River near Chewey, so estimated daily mean streamflows were computed by adding streamflow from Illinois River near Watts to streamflow from Flint Creek near Kansas (fig. 1, table 1).

Acknowledgments

The authors thank many people for their contributions to the data collection and data analysis presented in this report. There were numerous USGS personnel that participated in the bimonthly and runoff-event water-quality sampling, the entire Oklahoma Water Science Center Data Section at all three field offices added to the effort, but special thanks goes to the Tulsa Field Office for their contribution to the data collection. Additional special thanks go to Dave Lorenz for his help with load estimations, the S-LOADEST program, and his statistical guidance; Joel Galloway for his statistical guidance; and Dave Mueller for his insight into load estimation equations.

Methods

This section describes the water-quality collection and analysis protocol, method of streamflow separation into base flow and runoff, statistical tests used to compare groups of data, and methods used to estimate total phosphorus loads and yields.

Water-Quality Data Collection and Analysis

The USGS operates several continuous streamflow gaging stations and ungaged stations and collects water-quality data in the Illinois River basin in Oklahoma. Four continuous streamflow gaging stations were selected for use in this report: Illinois River near Watts, Flint Creek near Kansas, Illinois

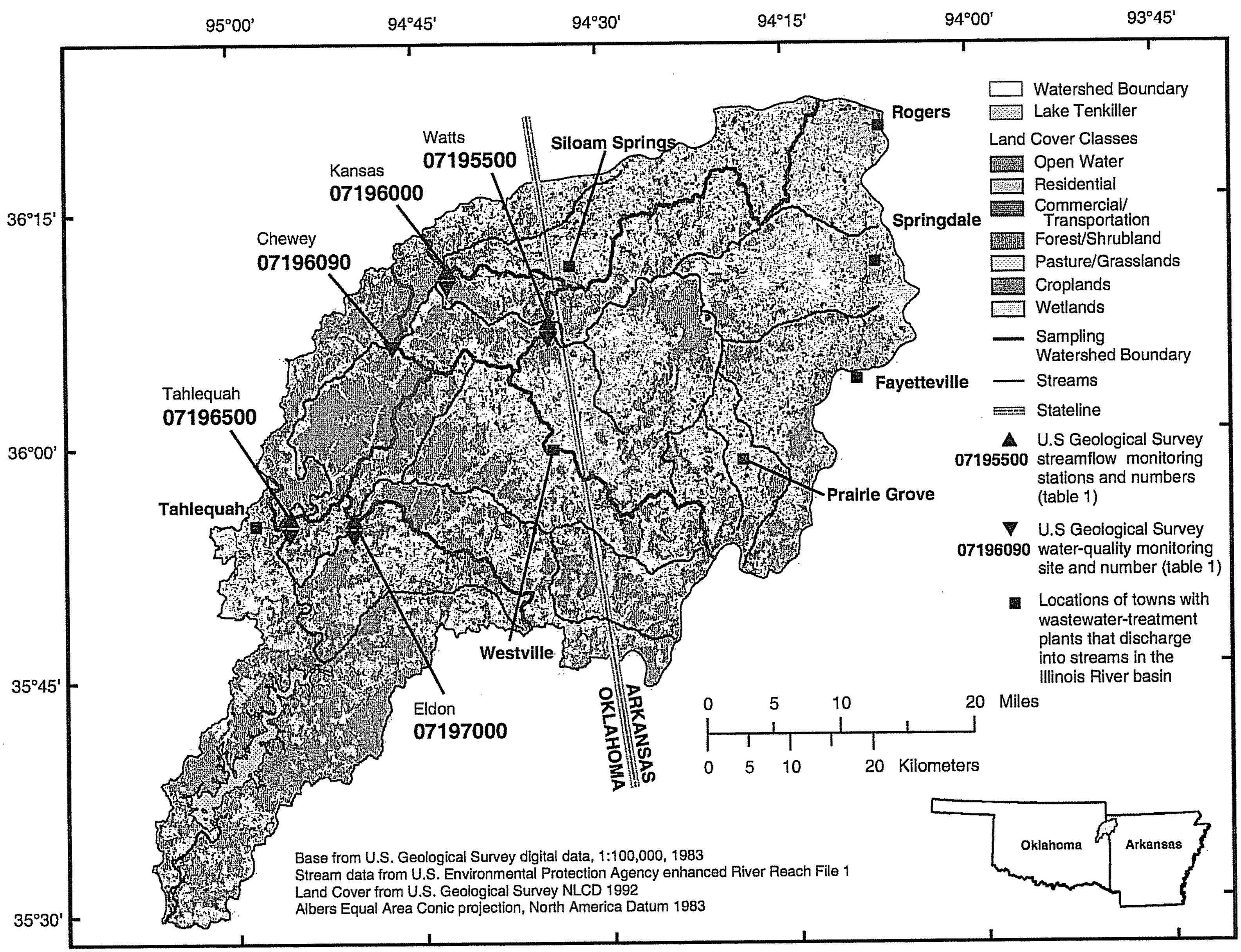

Figure 2. .Land use in the Illinois River basin, Arkansas and Oklahoma (Modified from Pickup and others, 2003)

Table 1. Station information and streamflow statistics for continuous streamflow gaging and ungaged stations used for water-quality monitoring in the Illinois River basin, Oklahoma.

[WY, water year; ddmmss, degrees, minutes, seconds; mi^2, square mile; ft^3/s, cubic foot per second; NA, not applicable]

Station name (number)	Period of record for station (WY)	Latitude (ddmmss)	Longi-tude (ddmmss)	Drainage area (mi^2)	Mean annual streamflow (ft^3/s)				Minimum and maximum daily mean streamflow for study period, 2000-2004 (ft^3/s)	
					2000-2002	2001-2003	2002-2004	Period of record[2]	Minimum (date)	Maximum (date)
Illinois River near Watts (07195500)	1955–present	360748	943419	635	639	539	552	631	83 (08/28/2003)	19,200 (04/24/2004)
Flint Creek near Kansas (07196000)	1955–1976; 1979–1990; 1993–present	361111	944224	110	105	77.7	93.6	119	10 (08/27/2003)	7,820 (06/21/2000)
Illinois River at Chewey (07196090)[1]	NA	360615	944657	820	745	616	645	NA	94 (08/28/2003)	26,000 (06/21/2000)
Illinois River near Tahlequah (07196500)	1936–present	355522	945524	959	990	787	829	940	93 (08/28/2003)	32,800 (06/22/2000)
Baron Fork at Eldon (07197000)	1949–present	355516	945018	307	327	250	270	330	23 (08/27/2003)	22,300 (06/21/2000)

[1]The Illinois River at Chewey is ungaged; streamflow is estimated by adding streamflow from Illinois River near Watts to streamflow from Flint Creek near Kansas.

[2]Based on streamflow statistics through Water Year 2004.

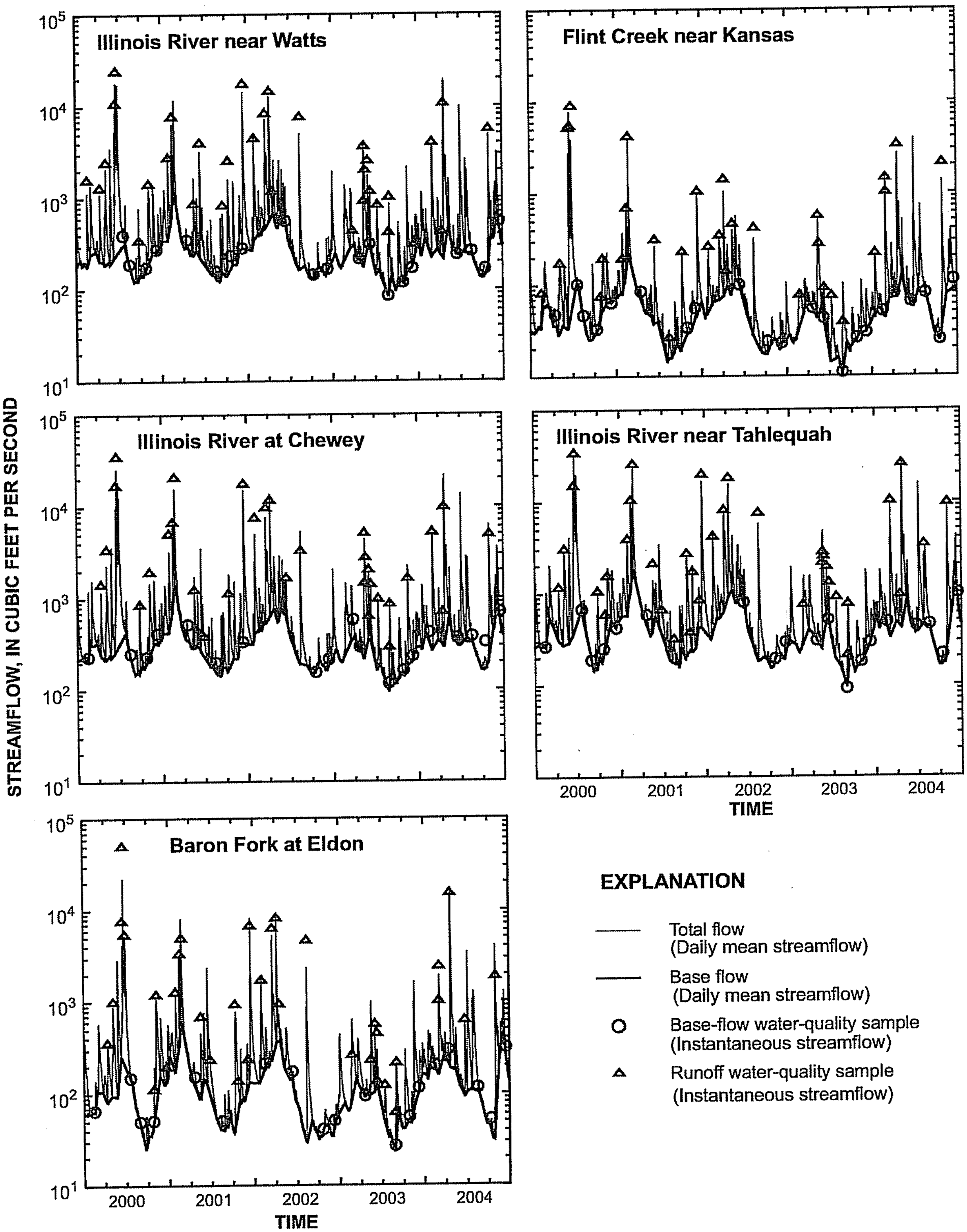

Figure 3. Streamflow divided into total flow and base flow, and base-flow and runoff water samples collected at water-quality stations in the Illinois River basin, Oklahoma, 2000–2004. Base flow estimated by Base-Flow Index program (Institute of Hydrology, 1980a, 1980b.)

River near Tahlequah, and Baron Fork at Eldon (table 1, fig. 1). The Illinois River at Chewey is an ungaged station at which streamflow is only measured when water-quality samples are collected (table 1, fig. 1). Stream gages were operated and streamflows were measured according to methods described in Rantz and others (1982). The data used for surface-water quality analyses should represent different flow conditions (from low to high) and be reasonably balanced among seasons (A.V. Vecchia, USGS, written commun., 2005). Prior to July 1999, only bimonthly water-quality samples were collected at these stations. Starting in July 1999, six additional water-quality samples were collected annually during runoff events at these stations (fig. 3). Representative water-quality samples were collected using equal-width increment methods (Edwards and Glysson, 1999).

The USGS National Water Quality Laboratory in Lakewood, Colorado, analyzed the water-quality samples for total phosphorus using methods described in Patton and Truitt (1992). The total phosphorus concentrations are reported as values if they are above the laboratory reporting level (LRL). The LRL is set to reduce false positive error, and is equal to twice the yearly determined long-term method detection level. Censored values are the value of the LRL reported with a "less than" remark code for samples in which the concentration was not detected. Estimated values are detected concentrations with concentrations between the long-term method detection level and the LRL are reported with an "E" remark code (Childress and others, 1999).

Streamflow data and phosphorus concentrations measured from 2000 through 2004 are analyzed in this report. All streamflow and water-quality data are available through the world wide web at *http://water.usgs.gov/ok/nwis*.

Streamflow Separation

Streamflow was separated into base-flow and runoff components using a hydrograph separation program, Base-Flow Index (Institute of Hydrology, 1980a, 1980b; Wahl and Wahl, 1995) (fig. 3). Base flow is the sustained runoff or fair-weather flow of the stream and is largely composed of ground-water seepage (Langbein and Iseri, 1960). The minimum daily mean flow was identified in consecutive 5-day increments, and minimums less than 90 percent of adjacent minimums were defined as turning points (Wahl and Wahl, 1988; Wahl and Tortorelli, 1997). The Base-Flow Index program estimated the base-flow hydrograph by drawing straight lines through successive turning points. Runoff components were calculated as the difference between total streamflow and base-flow components.

Each day was designated to be either base flow or runoff. Base-flow days in this report were defined as days when base flow was greater than or equal to 70 percent of total flow; runoff days were defined as days when runoff contributed more than 30 percent of total flow.

Statistical Tests

Streamflow data and water-quality data were divided into three 3-year periods: 2000–2002, 2001–2003, and 2002–2004, based on calendar year. Three-year periods were used to emulate a 3-year moving average.

The Mann-Whitney rank-sum test (Helsel and Hirsch, 1992), used to compare two groups of data, was used to determine the statistical significance of differences between base-flow and runoff phosphorus concentrations at each station within each period. The Kruskal-Wallis test (Helsel and Hirsch, 1992, p. 159, 355), used to compare multiple data sets at one time, was used to determine the statistical significance of differences in phosphorus concentrations among stations in the Illinois River basin within base-flow and runoff groups of data.

The tests were selected because neither test requires normally distributed data. The null hypotheses of both tests indicate that there are no differences in median concentrations between the data sets being compared. The null hypothesis was rejected and medians were described as being significantly different if the two-sided p-value of the test was less than or equal to 0.05 (Helsel and Hirsch, 1992). If the null hypothesis of the Kruskal-Wallis test was rejected and the medians were described as significantly different, the multiple-stage Kruskal-Wallis test, which is new Kruskal-Wallis tests on smaller subsets of data, was applied to determine which sites were different and which were not (Helsel and Hirsch, 1992).

All tests conducted included censored values (values less than the laboratory reporting level) entered as one-half the laboratory reporting level values for analyses during 2000–2004. This was done for two reasons: (1) to be consistent with Pickup and others (2003); and (2) a comparison using censored value summary statistics with the traditional summary statistics using the one-half substitution showed very little difference in the results. Two sites had no censored values, Flint Creek near Kansas and Illinois River at Chewey; two sites had only one censored value, Illinois River near Watts and Tahlequah; and one site had eight censored values, Baron Fork near Eldon (Appendixes 1-5).

Load and Yield Estimation

Linear regression was used to evaluate relations between total streamflow and phosphorus concentrations for each of the periods. Regression methods have been developed to estimate daily constituent loads, because water-quality data were collected intermittently. The regression method requires daily mean streamflow data and discrete water-quality samples collected over several years. Sample dates, times, instantaneous streamflows, and phosphorus concentrations used in this analysis are provided in Appendixes 1–5 and through the world wide web at *http://water.usgs.gov/ok/nwis*.

Linear regression models developed by S-LOADEST for the estimation of phosphorus loads for all 3-year periods at each station are listed in table 2. Constituent load (L) is the product of streamflow (Q) and the constituent concentration in the water (C) multiplied by a conversion factor for consistent units. Load is the amount of a constituent transported past a selected point in a stream in a given amount of time, usually one year. The S-LOADEST program (Dave Lorenz, USGS, written commun., 2006) was used to estimate constituent loads by the rating-curve method (Cohn and others, 1989; Crawford, 1991) in the Illinois River, Flint Creek, and Baron Fork. S-LOADEST is based on LOADEST (Crawford, 1999; Runkel and others, 2004) and is incorporated in the computer program S-Plus (Insightful Corporation, 2005) to facilitate graphical analysis and tabular results. S-LOADEST estimates rating-curve parameters and mean daily loads using several regression methods and a ratio estimator. Because some of the constituent concentrations included in this analysis were censored, parameters were estimated by the adjusted maximum likelihood estimation method (Cohn, 1988; Cohn and others, 1992). In the absence of censored data, the method converts to the maximum likelihood estimation method (Dempster and others, 1977; Wolynetz, 1979). An estimate of the uncertainty in the estimated load was obtained using the method described by Likes (1980) and Gilroy and others (1990). S-LOADEST contains nine predefined rating-curve models that can test the relation between constituent load and streamflow. The model used for this report (equation 1) includes a time variable and seasonality variables to model the relation between the natural logarithms of L, Q and Q^2:

$$ln(L) = b_0 + b_1\, lnQ + b_2\, lnQ^2 + b_3 T + b_4 \sin SS + b_5 \cos SS$$

where

ln	is natural logarithm
L	is constituent load, in pounds per day (lb/d);
b_0	is regression constant, dimensionless;
b_1, b_2, b_3, b_4, b_5	are regression coefficients, dimensionless;
Q	is daily mean streamflow, in cubic feet per second (ft^3/s);
T	is dectime, time parameter in decimal years;
sin	is sine;
cos	is cosine; and
SS	is seasonality parameter (2πdectime).

Data from stations on the Illinois River at Chewey and near Tahlequah, and Flint Creek, generally appeared to fit the model better than data from Illinois River near Watts and Baron Fork. Other S-LOADEST predefined regression models using various combinations of streamflow, time, and seasonal coefficients did have lesser residuals than the model used for this report; however, the "best" model indicated in S-LOADEST was different for each station and time. However, this one general model (equation 1) was chosen for all stations and periods: (1) to be consistent with general methodology in the previous Pickup and others (2003) report, (2) to use a consistent general model to estimate loads for all stations and periods in a basin, (3) because an analysis of the "best" models compared with this general model indicated a very small improvement in reduction in variance, and (4) because seasonality parameters were present in the majority of the "best" models and this general model had a much lower variance than the simpler model used in Pickup and others (2003).

Three-year periods were used to emulate a 3-year moving average. Different model coefficients for each 3-year period were used (1) to allow the slope between L and Q to vary with time instead of having one slope for the 5-year period, and (2) because the model variances were lower using different 3-year models instead of a single 5-year model, indicating a better model fit.

Estimated mean annual phosphorus loads and estimates of the standard deviations of the mean loads were calculated by S-LOADEST using all base-flow and runoff data. The daily load values generated by S-LOADEST were then separated into base-flow and runoff sample sets according to the number of base-flow days and the number of runoff days in each 3-year period. Estimated mean annual base-flow loads were calculated as the mean of the base-flow day sample set. Estimated mean annual runoff loads were calculated as the mean of the runoff day sample set. Estimated seasonal base-flow and runoff loads were calculated in the same way based on the number of base-flow and runoff days in each season of each period. In this report, spring is March through May, summer is June through August, fall is September through November, and winter is December through February.

Phosphorus yields for each of the three periods at each station were calculated by dividing mean annual phosphorus loads by drainage area (table 1). Flow-weighted concentrations for each of the three periods at each station were calculated by dividing mean annual phosphorus loads by mean annual streamflow and multiplying by a conversion factor to adjust the units.

Phosphorus Concentrations, Loads and Yields in the Illinois River Basin

Phosphorus in the Illinois River basin is described in terms of three 3-year periods (2000–2002, 2001–2003, and 2002–2004) of mean concentrations, loads, and yields in base-flow and runoff samples, and in terms of mean flow-weighted concentrations. All annual and seasonal loads, yields, and flow-weighted concentrations are estimated mean values that were calculated by S-LOADEST. All total phosphorus values are referred to as phosphorus.

Table 2. Regression models developed using total phosphorus concentrations from water samples collected at water-quality stations in the Illinois River basin, Oklahoma, periods 2000–2002, 2001–2003, and 2002–2004.

[no., number; obs., observations; ln, natural logarithm; L, daily load in pound per day; Q, mean daily streamflow in cubic foot per second; T, dectime, time parameter in decimal years; SS, seasonality parameter, (2πdectime); R^2, coefficient of determination]

Station name (number)	3-year period	No. of obs.	No. of censored obs.[1]	Regression model	Estimated residual variance[2]	R^2 (percent)
Illinois River near Watts (07195500)	2000–2002	30	1	$\ln(L) = 7.93 + 1.18*\ln Q + 0.0538*\ln Q^2 + 0.0643*T - 0.138*\sin SS + 0.0286*\cos SS$	0.314	93
	2001–2003	33	1	$\ln(L) = 7.55 + 1.24*\ln Q + 0.0352*\ln Q^2 - 0.116*T - 0.225*\sin SS - 0.101*\cos SS$	0.357	91
	2002–2004	31	0	$\ln(L) = 7.25 + 1.42*\ln Q + 0.0869*\ln Q^2 - 0.239*T - 0.351*\sin SS - 0.298*\cos SS$	0.224	96
Flint Creek near Kansas (07196000)	2000–2002	31	0	$\ln(L) = 6.29 + 1.42*\ln Q + 0.0491*\ln Q^2 + 0.0559*T - 0.120*\sin SS - 0.0784*\cos SS$	0.045	99
	2001–2003	30	0	$\ln(L) = 5.23 + 1.33*\ln Q + 0.0726*\ln Q^2 + 0.183*T - 0.0924*\sin SS - 0.0657*\cos SS$	0.029	99
	2002–2004	31	0	$\ln(L) = 5.42 + 1.28*\ln Q + 0.0716*\ln Q^2 + 0.0042*T - 0.0505*\sin SS - 0.0522*\cos SS$	0.031	99
Illinois River at Chewey (07196090)	2000–2002	27	0	$\ln(L) = 8.12 + 1.33*\ln Q + 0.0400*\ln Q^2 + 0.0587*T - 0.0220*\sin SS - 0.0254*\cos SS$	0.087	99
	2001–2003	32	0	$\ln(L) = 7.59 + 1.36*\ln Q + 0.0638*\ln Q^2 - 0.119*T - 0.185*\sin SS - 0.119*\cos SS$	0.084	98
	2002–2004	31	0	$\ln(L) = 7.04 + 1.45*\ln Q + 0.162*\ln Q^2 - 0.168*T - 0.257*\sin SS - 0.295*\cos SS$	0.062	99
Illinois River near Tahlequah (07196500)	2000–2002	31	1	$\ln(L) = 7.93 + 1.48*\ln Q + 0.0158*\ln Q^2 + 0.0491*T - 0.0906*\sin SS - 0.110*\cos SS$	0.059	99
	2001–2003	33	1	$\ln(L) = 7.37 + 1.45*\ln Q + 0.0586*\ln Q^2 + 0.0197*T - 0.102*\sin SS - 0.154*\cos SS$	0.070	99
	2002–2004	31	0	$\ln(L) = 7.13 + 1.46*\ln Q + 0.0838*\ln Q^2 - 0.257*T - 0.270*\sin SS - 0.214*\cos SS$	0.072	99
Baron Fork at Eldon (07197000)	2000–2002	32	8	$\ln(L) = 6.15 + 1.68*\ln Q + 0.0258*\ln Q^2 + 0.115*T - 0.466*\sin SS - 0.239*\cos SS$	0.276	98
	2001–2003	32	3	$\ln(L) = 5.26 + 1.60*\ln Q + 0.0689*\ln Q^2 - 0.0842*T - 0.389*\sin SS - 0.149*\cos SS$	0.182	98
	2002–2004	31	2	$\ln(L) = 5.32 + 1.71*\ln Q + 0.101*\ln Q^2 - 0.147*T - 0.377*\sin SS - 0.0890*\cos SS$	0.107	99

[1]Censored observations are a result of an analysis value lower than the laboratory minimum reporting level.

[2]Estimated residual variance is the maximum likelihood estimation variance corrected for the number of observations, number of censored observations, and number of parameters in the regression model.

Concentrations

Phosphorus concentrations were significantly greater ($p \leq 0.05$) in runoff samples than in base-flow samples for all three periods, 2000–2002, 2001–2003, and 2002–2004, at all stations (tables 3 and 4, fig. 4).

Phosphorus concentrations in base-flow samples during all 3-year periods significantly decreased ($p \leq 0.05$) in the downstream direction in the Illinois River from the Watts to Tahlequah stations (fig. 5), as has been reported for other point-source affected streams in the region (Haggard, 2000; Haggard and others, 2001). Phosphorus concentrations in base-flow samples from the Illinois River generally decreased with increasing streamflow (fig. 4, table 3). As base flow increased by addition of ground water, dilution reduced the concentration of phosphorus from point sources. The Illinois River and Flint Creek received phosphorus concentrations from point sources, but Baron Fork did not. Consequently, phosphorus concentrations in base-flow samples from Baron Fork were significantly less than those in base-flow samples from the Illinois River and Flint Creek during all 3-year periods (fig. 5).

Phosphorus concentrations in runoff samples for all 3-year periods were not significantly different among the two upstream stations on the Illinois River and Flint Creek for the periods 2000-2002 and 2001-2003; and not significantly different among the three stations on the Illinois River and Flint Creek for the periods 2002-2004 (fig. 6). However, the concentrations at Baron Fork were significantly less than at all other stations for all periods, except at Tahlequah during 2000-2002 (fig. 6). Phosphorus concentrations in runoff samples from the Illinois River, Flint Creek, and the Baron Fork generally increased with increasing streamflow (fig. 4). Possible causes of larger concentrations of phosphorus during runoff events than in base flow are resuspension of phosphorus from the streambed and lakebed sediment, stream bank erosion, and the addition of phosphorus from nonpoint sources. Svendsen and others (1995) reported that about half the phosphorus transported during runoff in lowland streams in Denmark resulted from resuspension of phosphorus in streambed sediments.

Estimated Mean Annual Loads

Estimated mean annual phosphorus loads were substantially greater at the Illinois River stations than at Flint Creek and Baron Fork, primarily because of greater streamflow at the stations on the Illinois River (tables 1 and 5). Annual total loads from Watts to Tahlequah in the Illinois River, increased slightly for the period 2000–2002 (table 5) and decreased slightly for the periods 2001–2003 and 2002–2004 (table 5).

Estimated mean annual base-flow loads were least in the Baron Fork, despite a larger drainage basin and greater base flow than Flint Creek, which receives phosphorus from wastewater discharges (fig. 2). Annual base-flow loads at stations on the Illinois River were about 11 to 20 times greater than base-flow loads at the station on Baron Fork and were about 4 to 10 times greater than base-flow loads at the station on Flint Creek. Annual base-flow phosphorus loads decreased from Watts to Tahlequah in the Illinois River within all three periods and between periods in the basin from 2000–2004 (table 5).

Estimated mean annual runoff loads in the basin increased with increasing drainage area and with increasing streamflow (tables 1 and 5). The portion of annual phosphorus load contributed by runoff increased in the downstream direction in the Illinois River (Watts to Tahlequah) (table 5). Runoff components of the annual total load for Flint Creek ranged from 68 to 84 percent from 2000 to 2004 (table 5). At the Illinois River stations, the range in the runoff component of the annual total load was 75 to 88 percent (table 5). Runoff components of the annual total load at Baron Fork ranged from 91 to 96 percent (table 5). These runoff loads were from small proportion of the time with less than 39 percent of the days including substantial runoff (runoff component greater than 30 percent of total flow) (table 6). Annual runoff loads appeared to be greater in the 2000–2002 period compared to the other two time periods at all stations in the basin. The most significant decrease occurred between the 2000–2002 period and the 2001–2003 period, which coincides with the drop in mean annual streamflow (table 1).

Estimated Mean Seasonal Loads

Estimated mean seasonal base-flow phosphorus loads generally were least in fall (September through November) and greatest in spring (March through May) for all periods at all stations in the Illinois River basin (table 7). The summer season (June through August) in the period 2002–2004 also was a high load season.

Estimated mean seasonal runoff phosphorus loads were least in fall for all periods at all stations. Runoff loads generally were greatest in summer (June through August) for the period 2000–2002, but were greatest in winter (December through February) for the period 2001–2003, and greatest in spring for the period 2002–2004. The shift in seasonal patterns between the 3-year periods may be a result of the sampling of large runoff events. For example, streamflows and phosphorus concentration data collected during runoff events in June 2000 (maximum streamflow event for most stations for the 2000–2002 period; table 1, fig. 3) and April 2004 (maximum streamflow event for Illinois River near Watts for the 2002–2004 period; table 1, fig. 3) may have been sufficient to shift the greatest seasonal loads from summer to spring at all stations from the period 2000–2002 to the period 2002–2004.

Estimated Mean Yields

Estimated mean total yields of phosphorus ranged from 192 to 811 pounds per year per square mile (lbs/yr/mi^2), with

Table 3. Summary statistics of total phosphorus concentrations from base-flow and runoff water samples collected at water-quality stations in the Illinois River basin, Oklahoma, periods 2000–2002, 2001–2003, and 2002–2004.

[Obs, number of observations; Cens obs, number of censored observations; mg/L, milligram per liter as P; <, less than the laboratory reporting level]

Station name (number)	3-year period	Total phosphorus concentrations											
		Base-flow						Runoff					
		Minimum (mg/L)	Median (mg/L)	Mean (mg/L)	Maximum (mg/L)	Obs	Cens obs[2]	Minimum (mg/L)	Median (mg/L)	Mean (mg/L)	Maximum (mg/L)	Obs	Cens obs[2]
Illinois River near Watts (07195500) [1]	2000–2002	0.18	0.31	0.31	0.54	11	0	<0.06	0.41	0.49	0.93	19	1
	2001–2003	0.10	0.22	0.26	0.54	12	0	<0.06	0.37	0.45	1.06	21	1
	2002–2004	0.07	0.15	0.20	0.54	12	0	0.04	0.37	0.44	1.06	19	0
Flint Creek near Kansas (07196000)	2000–2002	0.11	0.14	0.14	0.15	11	0	0.11	0.26	0.42	1.66	20	0
	2001–2003	0.11	0.15	0.16	0.20	11	0	0.11	0.23	0.28	0.85	19	0
	2002–2004	0.14	0.16	0.17	0.20	14	0	0.14	0.24	0.33	0.72	17	0
Illinois River at Chewey (07196090)	2000–2002	0.14	0.17	0.20	0.30	9	0	0.18	0.45	0.50	0.96	18	0
	2001–2003	0.09	0.15	0.17	0.30	10	0	0.15	0.28	0.38	0.86	22	0
	2002–2004	0.05	0.12	0.14	0.30	12	0	0.08	0.28	0.36	0.78	19	0
Illinois River near Tahlequah (07196500) [1]	2000–2002	0.07	0.11	0.10	0.15	9	0	<0.06	0.26	0.34	0.82	22	1
	2001–2003	0.06	0.11	0.11	0.15	9	0	<0.06	0.22	0.28	0.82	24	1
	2002–2004	0.04	0.09	0.09	0.15	13	0	0.06	0.24	0.30	0.82	18	0
Baron Fork at Eldon (07197000) [1]	2000–2002	<0.04	<0.04	<0.04	0.04	10	6	<0.05	0.14	0.32	1.65	22	2
	2001–2003	<0.04	<0.04	<0.04	0.04	11	3	0.02	0.09	0.16	0.74	21	0
	2002–2004	<0.04	<0.04	<0.04	0.04	14	2	0.02	0.09	0.23	1.08	17	0

[1]All concentration data, including censored data, were used to calculate statistics.

[2]Censored data (concentrations less than the laboratory reporting level) were entered in the calculations as one-half the laboratory reporting level.

Table 4. Wilcoxon rank-sum test results comparing base-flow total phosphorus concentrations to runoff total phosphorus concentrations from water samples collected at water-quality stations in the Illinois River basin, Oklahoma, periods 2000–2002, 2001–2003, and 2002–2004.

[z, normal test statistic with correction for ties; p, probability value; p-values in bold indicate statistically significant differences between groups of data at 95-percent confidence level (probability value less than or equal to 0.05)]

Station name (number)	3-year period[2]		
	2000–2002	2001–2003	2002–2004
Illinois River near Watts (07195500) [1]	z = -2.132 **p = 0.0330**	z = -2.115 **p = 0.0344**	z = -2.596 **p = 0.0094**
Flint Creek near Kansas (07196000)	z = -3.425 **p = 0.0006**	z = -3.049 **p = 0.0023**	z = -3.925 **p = 0.0001**
Illinois River at Chewey (07196090)	z = -3.345 **p = 0.0008**	z = -3.131 **p = 0.0017**	z = -3.630 **p = 0.0003**
Illinois River near Tahlequah (07196500) [1]	z = -3.574 **p = 0.0004**	z = -3.600 **p = 0.0003**	z = -4.104 **p < 0.0001**
Baron Fork at Eldon (07197000) [1]	z = -3.809 **p = 0.0001**	z = -4.021 **p = 0.0001**	z = -4.172 **p < 0.0001**

[1]All concentration data, including censored data, were used to calculate statistics.

[2]Censored data (concentrations less than the laboratory reporting level) were entered in the calculations as one-half the laboratory reporting level.

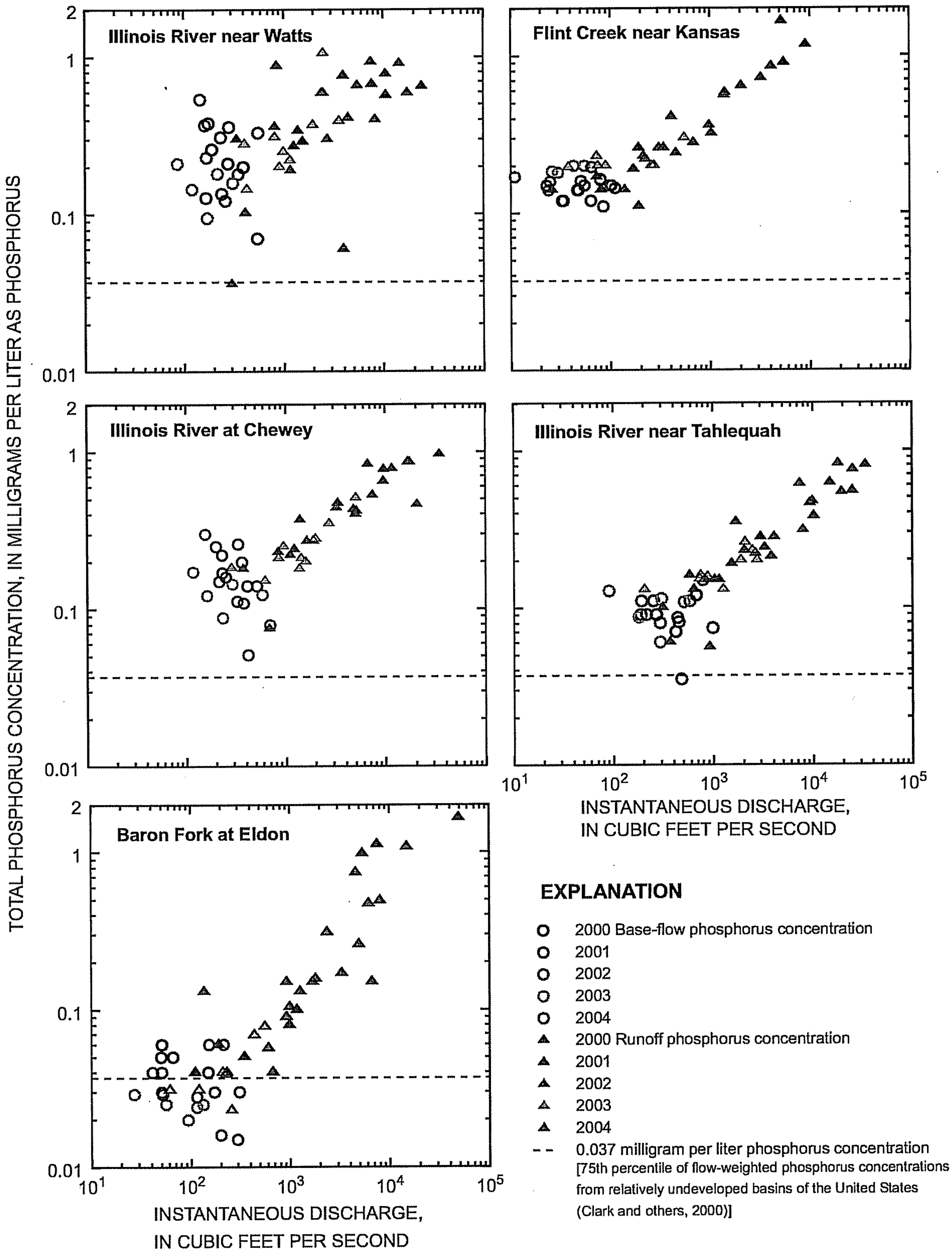

Figure 4. Total phosphorus concentrations from base-flow and runoff water samples collected at water-quality stations in the Illinois River basin, Oklahoma, 2000–2004.

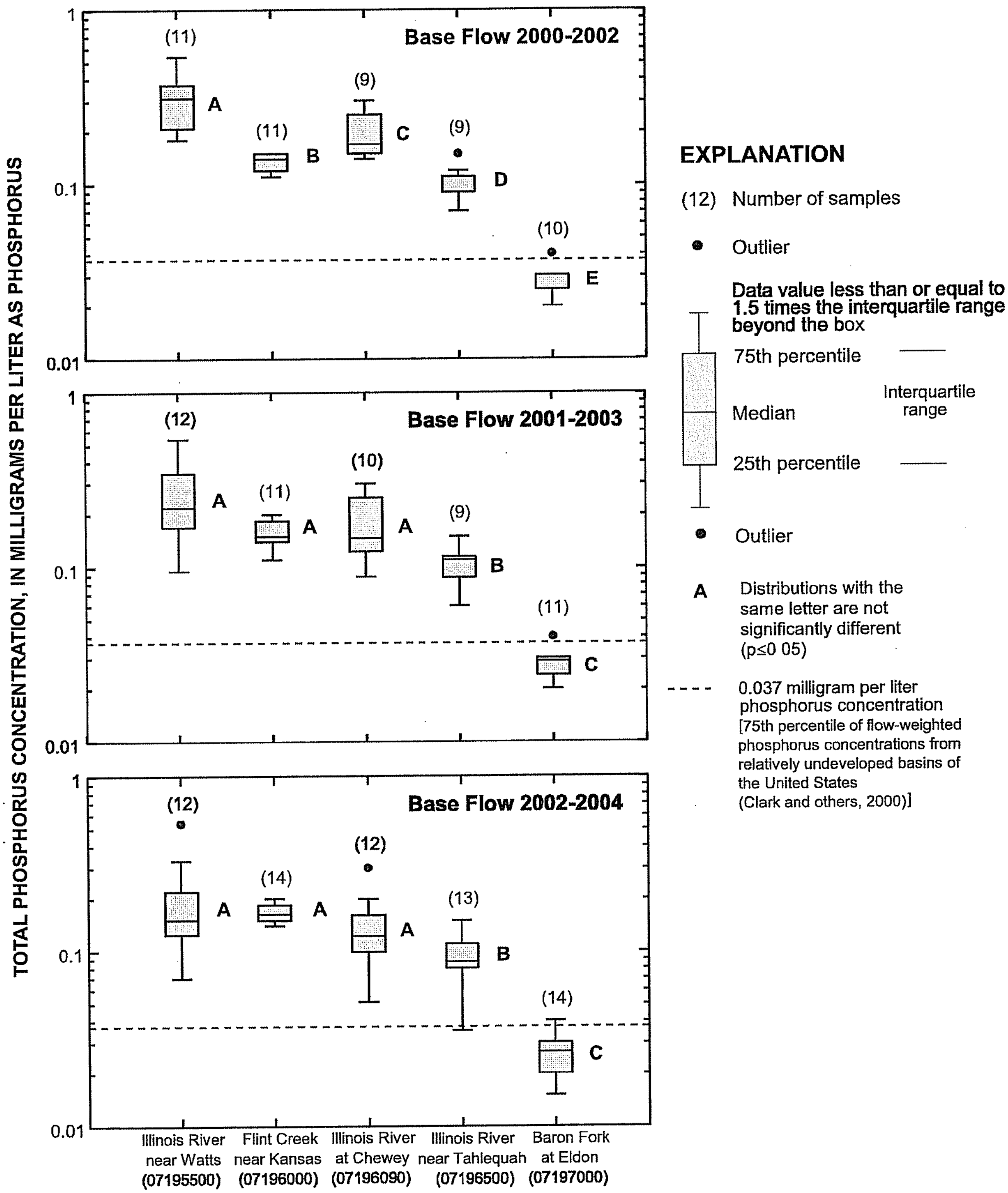

Figure 5. Distributions of **base-flow** total phosphorus concentrations from water samples collected at water-quality stations in the Illinois River basin, Oklahoma, periods 2000–2002, 2001–2003, and 2002–2004.

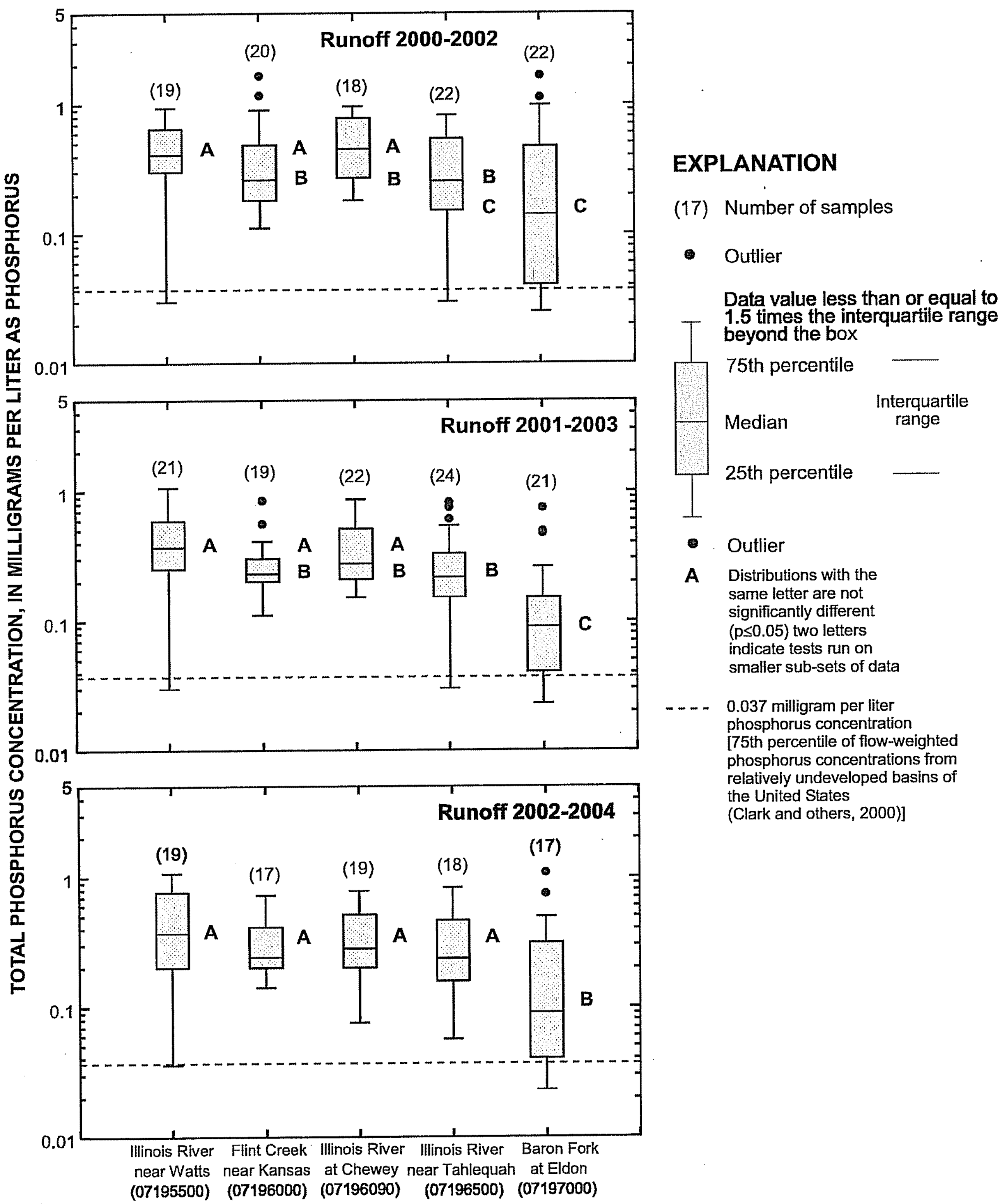

Figure 6. Distributions of **runoff** total phosphorus concentrations from water samples collected at water-quality stations in the Illinois River basin, Oklahoma, periods 2000–2002, 2001–2003, and 2002–2004.

Table 5. Estimated mean annual total phosphorus loads and yields estimated from total phosphorus concentrations in water samples collected at water-quality stations in the Illinois River basin, Oklahoma, periods 2000–2002, 2001–2003, and 2002–2004.

[mi², square mile; lb/yr, pound per year; lb/yr/mi², pound per year per square mile; SEP, standard error of prediction; P, phosphorus. Differences between total load and the sum of the base-flow load plus runoff loads are due to rounding.]

Station name (number)	Drainage area (mi²)	3-year period	Estimated mean annual total phosphorus: Total load [1] (+/- SEP[1]) (lb/yr as P)	Total yield (lb/yr/mi² as P)	Base-flow load [2] (lb/yr as P)	Base-flow yield (lb/yr/mi² as P)	Runoff load [3] (lb/yr as P)	Runoff yield (lb/yr/mi² as P)	Load delivered during runoff (percent)
Illinois River near Watts (07195500)	635	2000–2002	515,000 (71,500)	811	116,000	182	399,000	629	78
		2001–2003	384,000 (62,600)	604	96,100	151	288,000	453	75
		2002–2004	366,000 (53,400)	576	63,900	101	302,000	476	82
Flint Creek near Kansas (07196000)	110	2000–2002	70,000 (6,340)	637	11,100	101	58,900	536	84
		2001–2003	32,300 (1,590)	293	10,200	93.0	22,000	200	68
		2002–2004	49,500 (2,610)	450	12,000	109	37,500	341	76
Illinois River at Chewey (07196090)	820	2000–2002	549,000 (43,100)	670	94,900	116	454,000	554	83
		2001–2003	348,000 (27,000)	425	77,300	94.2	271,000	330	78
		2002–2004	405,000 (45,800)	494	59,100	72.1	346,000	422	85
Illinois River near Tahlequah (07196500)	959	2000–2002	559,000 (40,000)	583	65,700	68.5	493,000	514	88
		2001–2003	331,000 (24,000)	346	60,900	63.5	271,000	282	82
		2002–2004	355,000 (29,400)	370	53,400	55.7	302,000	314	85
Baron Fork at Eldon (07197000)	307	2000–2002	154,000 (45,400)	501	5,660	18.4	148,000	482	96
		2001–2003	59,000 (10,100)	192	5,360	17.5	53,600	175	91
		2002–2004	120,000 (28,400)	389	5,000	16.3	115,000	373	96

[1]Calculated by S-LOADEST and are statistics of all data in the 3-year period.

[2]Means of the base-flow loads are calculated from base-flow days data only.

[3]Means of the runoff loads are calculated from runoff days data only.

Table 6. Number of days of base flow and runoff designated by Base-Flow Index (BFI) program at water-quality stations in the Illinois River basin, Oklahoma, periods 2000–2002, 2001–2003, and 2002–2004.

[Spring is March through May, Summer is June through August, Fall is September through November, and Winter is December through February]

Station name (number)	3-year period	Spring		Summer		Fall		Winter		Total		Percent of runoff days in period
		Base flow	Runoff	Base flow	Runoff	Base flow	Runoff	Base flow	Runoff	Base flow	Runoff	
Illinois River near Watts (07195500)	2000–2002	168	108	180	96	208	65	153	118	709	387	35
	2001–2003	169	107	206	70	200	73	145	125	720	375	34
	2002–2004	136	140	198	78	215	58	176	95	725	371	34
Flint Creek near Kansas (07196000)	2000–2002	188	88	185	91	197	76	188	83	758	338	31
	2001–2003	196	80	189	87	193	80	177	93	755	340	31
	2002–2004	157	119	173	103	205	68	192	79	727	369	34
Illinois River at Chewey (07196090)	2000–2002	169	107	181	95	209	64	155	116	714	382	35
	2001–2003	175	101	207	69	201	72	147	123	730	365	33
	2002–2004	140	136	197	79	211	62	177	94	725	371	34
Illinois River near Tahlequah (07196500)	2000–2002	165	111	164	112	195	78	149	122	673	423	39
	2001–2003	166	110	182	94	195	78	149	121	692	403	37
	2002–2004	128	148	189	87	210	63	178	93	705	391	36
Baron Fork at Eldon (07197000)	2000–2002	159	117	185	91	207	66	139	132	690	406	37
	2001–2003	179	97	204	72	202	71	132	138	717	378	34
	2002–2004	156	120	194	82	208	65	171	100	729	367	34

Table 7. Estimated mean seasonal total phosphorus loads estimated from total phosphorus concentrations in water samples collected at water-quality stations in the Illinois River basin Oklahoma, periods 2000–2002, 2001–2003, and 2002–2004.

[Values are loads in pound per season as total phosphorus, Spring is March through May, Summer is June through August, Fall is September through November, and Winter is December through February]

Flow type	Station name (number)	Estimated mean seasonal total phosphorus loads			
		Spring	Summer	Fall	Winter
	2000–2002				
Base flow	Illinois River near Watts (07195500)	34,900	28,100	24,800	28,000
	Flint Creek near Kansas (07196000)	3,900	2,760	1,440	3,000
	Illinois River at Chewey (07196090)	34,100	22,700	15,400	22,700
	Illinois River near Tahlequah (07196500)	27,700	15,400	7,710	14,900
	Baron Fork at Eldon (07197000)	2,430	1,320	643	1,270
Runoff	Illinois River near Watts (07195500)	95,600	145,000	25,600	133,000
	Flint Creek near Kansas (07196000)	6,070	39,200	2,000	11,700
	Illinois River at Chewey (07196090)	104,000	192,000	19,500	139,000
	Illinois River near Tahlequah (07196500)	99,000	240,000	19,900	135,000
	Baron Fork at Eldon (07197000)	20,400	95,200	3,450	29,000
	2001–2003				
Base flow	Illinois River near Watts (07195500)	31,500	26,400	17,500	20,800
	Flint Creek near Kansas (07196000)	4,260	2,130	1,380	2,460
	Illinois River at Chewey (07196090)	27,800	20,500	12,500	16,400
	Illinois River near Tahlequah (07196500)	25,800	14,200	7,670	13,200
	Baron Fork at Eldon (07197000)	2,430	930	685	1,320
Runoff	Illinois River near Watts (07195500)	96,200	35,300	22,800	133,000
	Flint Creek near Kansas (07196000)	6,910	2,150	1,420	11,600
	Illinois River at Chewey (07196090)	88,600	28,300	16,600	137,000
	Illinois River near Tahlequah (07196500)	94,400	26,700	14,300	135,000
	Baron Fork at Eldon (07197000)	15,700	4,500	2,360	31,100
	2002–2004				
Base flow	Illinois River near Watts (07195500)	16,300	22,700	12,900	12,100
	Flint Creek near Kansas (07196000)	4,080	3,200	2,000	2,730
	Illinois River at Chewey (07196090)	15,800	20,500	11,600	11,200
	Illinois River near Tahlequah (07196500)	16,400	16,900	8,710	11,400
	Baron Fork at Eldon (07197000)	1,860	868	802	1,470
Runoff	Illinois River near Watts (07195500)	188,000	69,100	17,700	26,900
	Flint Creek near Kansas (07196000)	18,400	12,800	3,330	2,950
	Illinois River at Chewey (07196090)	228,000	80,300	16,900	21,400
	Illinois River near Tahlequah (07196500)	201,000	60,800	17,200	22,900
	Baron Fork at Eldon (07197000)	97,000	7,490	6,540	3,560

greatest yields being reported for Illinois River near Watts (576 to 811 lbs/yr/mi^2), and the least yields being reported for Baron Fork at Eldon for the periods 2000–2002 and 2001–2003 (501 and 192 lbs/yr/mi^2) and for Illinois River near Tahlequah for the period 2002–2004 (370 lbs/yr/mi^2) (table 5). The greater yields in Illinois River near Watts may be caused by resuspension of phosphorus from the streambed and the lakebed of Lake Frances, stream bank erosion, and the addition of phosphorus from nonpoint sources.

Estimated mean base-flow yields decreased at the Illinois River stations and remained about the same on Flint Creek and Baron Fork over the three periods. Base-flow yields also decreased downstream in the Illinois River possibly because of dilution.

Estimated mean runoff yields appeared to be greater in the 2000–2002 period compared to the other two time periods at all stations in the basin. The most substantial decrease occurred between the 2000–2002 period and the 2001–2003 period. Because yield (mean load divided by drainage area) is proportional to load, this decrease again might be partly attributable to the drop in mean annual streamflow (table 1).

Estimated Mean Flow-Weighted Concentrations

Estimated mean flow-weighted phosphorus concentrations at the stations in the basin were more than 10 times greater than the median flow-weighted concentrations (0.022 mg/L) and were consistently greater than the 75th percentile of flow-weighted phosphorus concentrations in relatively undeveloped basins of the United States (0.037 mg/L, Clark and others, 2000; fig. 7, table 8). In addition, flow-weighted phosphorus concentrations in 2000–2002 at all Illinois River stations and at Flint Creek were approximately equal to or greater than the 75th percentile of all National Water-Quality Assessment program stations in the United States (0.29 mg/L, David Mueller, U.S. Geological Survey, written commun., 2003).

Estimated mean flow-weighted phosphorus concentrations were consistently greater than the median phosphorus concentrations shown in figure 7. The collected water-quality data has a wide range (table 3) and high outliers can greatly effect the computation of the mean flow-weighted concentrations. For example, the maximum concentration during 2002–2004 at Baron Fork at Eldon (1.08 mg/L, table 3) was collected during a high runoff event in April 2004 and resulted in a large mean annual load that was proportionally a much greater increase from 2001–2003 than all other stations (table 5). This resulted in a large increase in estimated mean flow-weighted phosphorus concentration from 2001–2003 to 2002–2004 at Baron Fork at Eldon (fig. 7).

Estimated Mean Annual Phosphorus Loads into Lake Tenkiller

Estimated mean annual phosphorus loads entering Lake Tenkiller can be estimated by adding the loads of Baron Fork and the Illinois River near Tahlequah. Phosphorus loads at these stations do not represent the entire phosphorus load into Lake Tenkiller, but the drainage area of these stations accounts for more than 80 percent of the drainage basin of the lake.

The Illinois River and Baron Fork contributed a mean annual phosphorus load that ranged from about 391,000 pounds per year (lbs/yr) to 712,000 lbs/yr (table 9) and from about 83 to 90 percent of the annual phosphorus load was transported to Lake Tenkiller by runoff. The Illinois River transported about 10 times more phosphorus load during base flow and about 3 times more phosphorus load during runoff to the lake than Baron Fork (table 9).

Summary

The Illinois River and tributaries, Flint Creek and the Baron Fork, are designated scenic rivers in Oklahoma. Streams in the Illinois River basin are susceptible to potentially large concentrations of phosphorus from point sources and nonpoint sources. Recent phosphorus levels in streams in the basin have resulted in excess algae growth, which have limited the aesthetic benefits of water bodies in the basin, especially the Illinois River and Lake Tenkiller. The Oklahoma Water Resources Board has established a standard for total phosphorus not to exceed the 30-day geometric mean concentration of 0.037 milligram per liter of phosphorus in Oklahoma Scenic Rivers.

In July 1999, the U.S. Geological Survey, in cooperation with the Oklahoma Scenic Rivers Commission and the Oklahoma Water Resources Board, supplemented fixed period, bimonthly water-quality sampling with six runoff-event samplings per year to better determine water quality over the range of streamflows in the basin. Phosphorus concentrations, loads, and yields were determined from January 2000 through December 2004, and for three 3-year periods—2000–2002, 2001–2003, and 2002–2004.

Phosphorus concentrations in the Illinois River basin were significantly greater in runoff samples than in base-flow samples. Phosphorus concentrations generally decreased with increasing base flow, from dilution, and decreased in the downstream direction in the Illinois River from the Watts to Tahlequah stations. Phosphorus concentrations generally increased with runoff, possibly because of phosphorus resuspension, stream bank erosion, and the addition of phosphorus from nonpoint sources.

Estimated mean annual phosphorus loads were greater at the Illinois River stations than at Flint Creek and Baron Fork. Annual total loads from Watts to Tahlequah in the

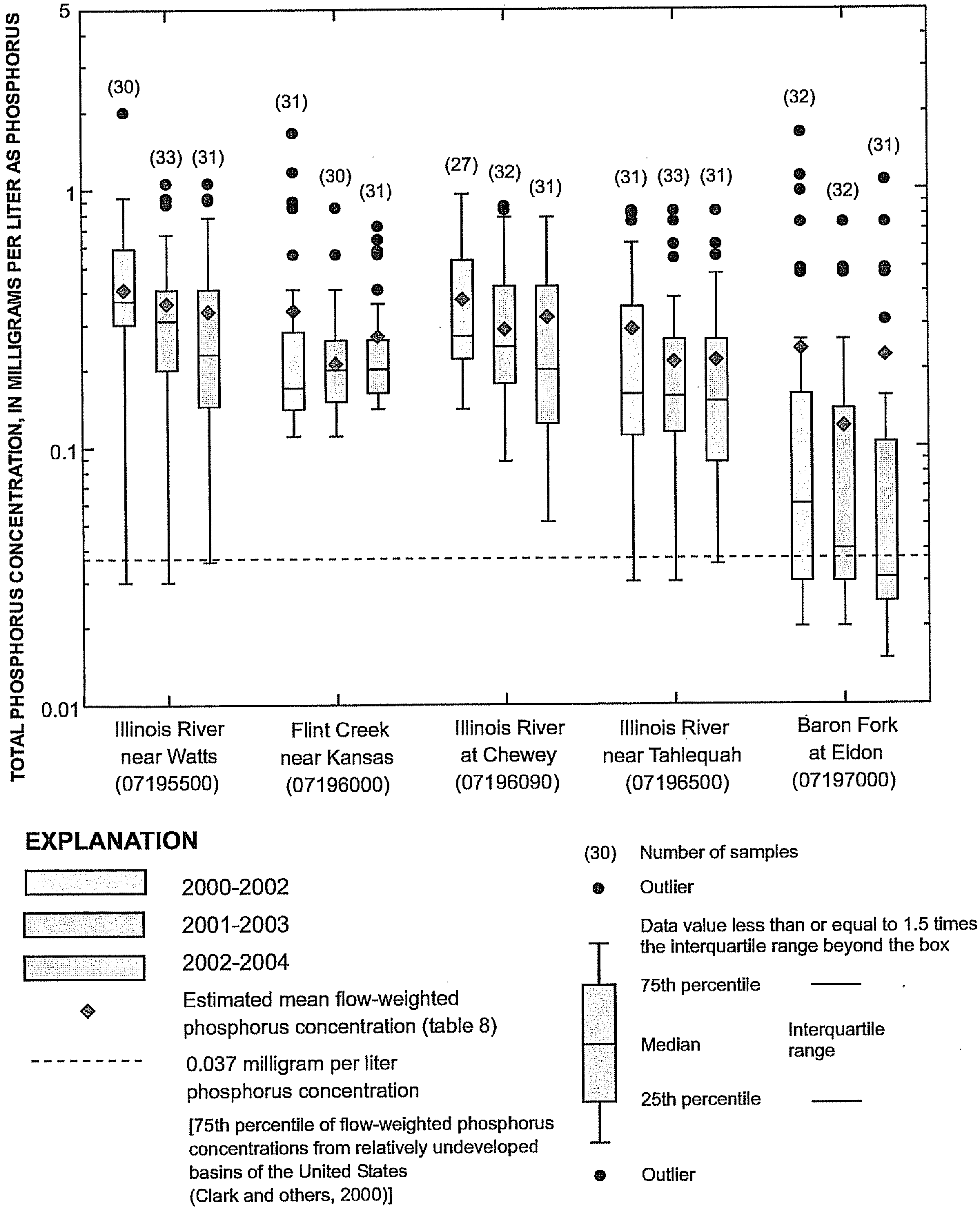

Figure 7. Instantaneous total phosphorus concentrations from water samples collected at water-quality stations in the Illinois River basin, Oklahoma, periods 2000–2002, 2001–2003, and 2002–2004. Mean flow-weighted total phosphorus concentrations are calculated from loads estimated by S-LOADEST.

Table 8. Estimated mean annual total phosphorus loads, mean annual streamflows, and mean flow-weighted total phosphorus concentrations at water-quality stations in the Illinois River basin, Oklahoma, periods 2000–2002, 2001–2003, and 2002–2004.

[lb/yr, pound per year; ft³/s, cubic foot per second; mg/L, milligram per liter]

Station name (number)	3-year period	Estimated mean annual: Total phosphorus load (lb/yr)	Estimated mean annual: Streamflow for 3-year period (ft³/s)	Estimated mean annual: Flow-weighted total phosphorus concentration (mg/L)
Illinois River near Watts (07195500)	2000–2002	515,000	639	0.409
	2001–2003	384,000	539	0.362
	2002–2004	366,000	552	0.337
Flint Creek near Kansas (07196000)	2000–2002	70,000	105	0.339
	2001–2003	32,300	77.7	0.211
	2002–2004	49,500	93.6	0.269
Illinois River at Chewey (07196090)	2000–2002	549,000	745	0.374
	2001–2003	348,000	616	0.287
	2002–2004	405,000	645	0.319
Illinois River near Tahlequah (07196500)	2000–2002	559,000	990	0.287
	2001–2003	331,000	787	0.214
	2002–2004	355,000	829	0.217
Baron Fork at Eldon (07197000)	2000–2002	154,000	327	0.239
	2001–2003	59,000	250	0.120
	2002–2004	120,000	270	0.226

Illinois River increased slightly for the period 2000–2002 and decreased slightly for the period 2001–2003 and 2002–2004.

Estimated mean annual base-flow loads at stations on the Illinois River were about 11 to 20 times greater than base-flow loads at the station on Baron Fork and 4 to 10 times greater than base-flow loads at the station on Flint Creek. Estimated mean annual runoff phosphorus loads increased with increasing drainage area and increasing streamflow. Runoff components of the annual total phosphorus load ranged from 68 to 96 percent from 2000–2004.

Estimated mean seasonal base-flow loads were generally greatest in spring (March through May) and were least in fall (September through November). Estimated mean seasonal runoff loads generally were greatest in summer (June through August) for the period 2000–2002, but were greatest in winter (December through February) for the period 2001–2003, and greatest in spring for the period 2002–2004.

Estimated mean total yields of phosphorus ranged from 192 to 811 pounds per year per square mile, with greatest yields being reported for Illinois River near Watts (576 to 811 pounds per year per square mile), and the least yields being reported for Baron Fork at Eldon for the periods 2000–2002 and 2001–2003 (501 and 192 pounds per year per square mile) and for Illinois River near Tahlequah for the period 2002–2004 (370 pounds per year per square mile). Estimated mean annual base-flow yields generally decreased at the Illinois River stations and remained about the same on Flint Creek and Baron Fork over the three periods. Base-flow yields also decreased downstream in the Illinois River possibly because of dilution. Estimated mean annual runoff yields appeared to decrease from the 2000–2002 period compared to the other two time periods at all stations in the basin. The most substantial decrease occurred between the 2000–2002 period and the 2001–2003 period.

Estimated mean flow-weighted concentrations were more than 10 times greater than the median and were consistently greater than the 75th percentile of flow-weighted phosphorus concentrations in samples collected at relatively undeveloped basins of the United States (0.022 milligram per liter and 0.037 milligram per liter, respectively). In addition, flow-weighted phosphorus concentrations in 2000–2002 at all Illinois River stations and at Flint Creek were equal to or greater than the 75th percentile of all National Water-Quality Assessment Program stations in the United States (0.29 milligram per liter).

The Illinois River and Baron Fork contributed an estimated mean annual load that ranged from about 391,000 pounds per year to 712,000 pounds per year and from about 83

Table 9. Summary of estimated total phosphorus loads to Lake Tenkiller, Oklahoma, periods 2000–2002, 2001–2003, and 2002–2004.

[lb/yr, pound per year]

Flow type	3-year period	Lake Tenkiller	Illinois River near Tahlequah	Baron Fork at Eldon
		Estimated mean annual phosphorus load [1] per period (lb/yr)	Component per period (percent)	Component per period (percent)
Base flow [2]	2000–2002	71,400	92	8
	2001–2003	66,300	92	8
	2002–2004	58,400	91	9
Runoff [3]	2000–2002	641,000	77	23
	2001–2003	325,000	83	17
	2002–2004	417,000	72	28
Total [4]	2000–2002	712,000	78	22
	2001–2003	391,000	85	15
	2002–2004	475,000	75	25

[1]Loads to Lake Tenkiller are calculated by adding loads from Illinois River near Tahlequah to loads from Baron Fork at Eldon (table 5).

[2]Means of the base-flow loads are calculated from base-flow day data only by S-LOADEST and are statistics of all data in the 3-year period.

[3]Means of the runoff loads are calculated from runoff day data only by S-LOADEST and are statistics of all data in the 3-year period.

[4]Differences between total loads and the sum of the base-flow loads plus runoff loads are due to rounding.

to 90 percent of the estimated mean annual phosphorus load was transported to Lake Tenkiller by runoff.

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Appendixes

Appendix 1. Instantaneous streamflows, total phosphorus concentrations, and flow category for Illinois River near Watts, Oklahoma, from 2000–2004.

[ft³/s, cubic foot per second; mg/L, milligram per liter; P, phosphorus; <, less than the laboratory reporting level; all water-quality and streamflow data available at *http://water.usgs.gov/ok/nwis*]

Date	Sample time	Instantaneous streamflow (ft³/s)	Total phosphorus concentrations (mg/L as P) [1]	Flow category [2]
02/18/2000	0835	1,560	0.29	Runoff
04/12/2000	0920	1,270	0.27	Runoff
05/07/2000	1052	2,410	0.59	Runoff
06/18/2000	0950	10,600	0.57	Runoff
06/22/2000	0745	24,100	0.65	Runoff
07/18/2000	1345	398	0.20	Base flow
08/15/2000	1445	191	0.26	Base flow
09/26/2000	1530	341	0.30	Runoff
10/24/2000	1030	176	0.38	Base flow
11/07/2000	0720	1,400	0.34	Runoff
12/08/2000	1430	279	0.21	Base flow
01/30/2001	1100	2,740	0.30	Runoff
02/15/2001	1100	7,660	0.67	Runoff
04/18/2001	1115	352	0.18	Base flow
05/18/2001	1120	851	0.88	Runoff
06/15/2001	1230	3,930	<0.06	Runoff
08/15/2001	1530	163	0.37	Base flow
09/18/2001	1250	815	0.36	Runoff
10/11/2001	1230	2,490	0.59	Runoff
10/23/2001	0800	236	0.31	Base flow
12/11/2001	1515	284	0.36	Base flow
12/17/2001	1420	17,300	0.59	Runoff
02/01/2002	1115	4,400	0.41	Runoff
03/20/2002	1108	8,210	0.40	Runoff
04/08/2002	1215	14,400	0.91	Runoff
04/17/2002	0755	1,170	0.19	Runoff
06/12/2002	1515	562	0.33	Base flow
08/14/2002	1640	7,490	0.93	Runoff
10/10/2002	0730	146	0.54	Base flow
12/09/2002	1400	169	0.23	Base flow
03/27/2003	1030	429	0.144	Runoff
04/23/2003	1045	219	0.181	Base flow
05/16/2003	1400	911	0.200	Runoff
05/17/2003	0920	3,590	0.390	Runoff

Appendix 1. Instantaneous streamflows, total phosphorus concentrations, and flow category for Illinois River near Watts, Oklahoma, from 2000–2004.—Continued

[ft³/s, cubic foot per second; mg/L, milligram per liter; P, phosphorus; <, less than the laboratory reporting level; all water-quality and streamflow data available at *http://water.usgs.gov/ok/nwis*]

Date	Sample time	Instantaneous streamflow (ft³/s)	Total phosphorus concentrations (mg/L as P) [1]	Flow category [2]
05/21/2003	1150	1,970	0.370	Runoff
06/02/2003	1145	2,490	1.060	Runoff
06/10/2003	0745	312	0.158	Base flow
06/12/2003	1250	1,160	0.220	Runoff
07/14/2003	1355	817	0.310	Runoff
08/28/2003	1100	86	0.210	Base flow
08/30/2003	1815	410	0.280	Runoff
09/02/2003	1200	997	0.250	Runoff
10/30/2003	0800	120	0.144	Base flow
12/08/2003	1630	171	0.095	Base flow
02/18/2004	1500	301	0.036	Runoff
03/04/2004	1115	3,930	0.760	Runoff
04/13/2004	1100	416	0.102	Runoff
04/23/2004	1540	10,500	0.780	Runoff
06/17/2004	1430	241	[3] E0.135	Base flow
08/17/2004	1345	260	0.122	Base flow
10/14/2004	1540	167	0.127	Base flow
11/01/2004	1530	5,450	0.660	Runoff
12/16/2004	1000	548	0.070	Base flow

[1]Year 2003 and 2004 values are reported as 3 significant digits because the precision of the analytical method changed.

[2]Base flow and runoff designated by Base-Flow Index (BFI) program (Institute of Hydrology, 1980a, 1980b).

[3] Rerun analyzed past analyical method holding time limit.

Appendix 2. Instantaneous streamflows, total phosphorus concentrations, and flow category for Flint Creek near Kansas, Oklahoma, from 2000–2004.

[ft³/s, cubic foot per second; mg/L, milligram per liter; P, phosphorus; all water-quality and streamflow data available at *http://water.usgs.gov/ok/nwis*]

Date	Sample time	Instantaneous streamflow (ft³/s)	Total phosphorus concentration (mg/L as P) [1]	Flow category [2]
02/18/2000	0830	81	0.14	Runoff
04/17/2000	1200	48	0.14	Base flow
05/07/2000	0922	170	0.19	Runoff
06/17/2000	1200	5,150	1.66	Runoff
06/21/2000	1700	5,450	0.90	Runoff
06/28/2000	1430	8,970	1.17	Runoff
07/19/2000	1520	102	0.15	Base flow
08/15/2000	0730	47	0.14	Base flow
10/11/2000	1230	33	0.12	Base flow
10/27/2000	1100	73	0.17	Runoff
11/06/2000	2000	191	0.26	Runoff
12/12/2000	1020	64	0.12	Base flow
01/29/2001	1130	191	0.11	Runoff
02/15/2001	0830	678	0.28	Runoff
02/24/2001	1435	4,090	0.85	Runoff
04/17/2001	1335	85	0.11	Base flow
06/15/2001	1040	304	0.26	Runoff
08/14/2001	1035	26	0.14	Runoff
10/11/2001	1045	224	0.22	Runoff
10/30/2001	1430	34	0.12	Base flow
12/06/2001	1330	55	0.15	Base flow
12/17/2001	1045	1,030	0.32	Runoff
02/01/2002	0915	256	0.20	Runoff
03/20/2002	0948	339	0.26	Runoff
04/08/2002	1115	1,390	0.56	Runoff
04/16/2002	1145	139	0.14	Runoff
05/13/2002	1130	454	0.24	Runoff
06/11/2002	1555	100	0.15	Base flow
08/14/2002	1125	407	0.41	Runoff
10/10/2002	1130	24	0.14	Base flow
12/10/2002	1600	23	0.15	Base flow
02/25/2003	1100	75	0.200	Runoff
04/22/2003	1000	55	0.200	Base flow
05/16/2003	1940	550	0.300	Runoff

Appendix 2. Instantaneous streamflows, total phosphorus concentrations, and flow category for Flint Creek near Kansas, Oklahoma, from 2000–2004.—Continued

[ft³/s, cubic foot per second; mg/L, milligram per liter; P, phosphorus; all water-quality and streamflow data available at *http://water.usgs.gov/ok/nwis*]

Date	Sample time	Instantaneous streamflow (ft³/s)	Total phosphorus concentration (mg/L as P)[1]	Flow category[2]
05/21/2003	1030	273	0.200	Runoff
06/09/2003	1215	43	0.200	Base flow
06/11/2003	1400	90	0.200	Runoff
07/14/2003	1220	73	0.230	Runoff
08/28/2003	1600	11	0.170	Base flow
08/31/2003	0115	38	0.196	Runoff
10/30/2003	0940	26	0.184	Base flow
12/09/2003	0800	30	0.181	Base flow
01/18/2004	1010	214	0.230	Runoff
02/18/2004	1130	51	0.160	Base flow
03/04/2004	0945	1,410	0.580	Runoff
03/05/2004	1130	984	0.360	Runoff
04/08/2004	1400	80	0.164	Base flow
04/24/2004	1040	3,230	0.720	Runoff
06/18/2004	0830	65	0.196	Base flow
08/18/2004	1235	80	0.162	Base flow
10/18/2004	1245	25	0.158	Base flow
11/01/2004	1325	2,050	0.640	Runoff
12/17/2004	1430	112	0.144	Base flow

[1]Year 2003 and 2004 values are reported as 3 significant digits because the precision of the analytical method changed.

[2]Base flow and runoff designated by Base-Flow Index (BFI) program (Institute of Hydrology, 1980a, 1980b).

Appendix 3. Instantaneous streamflows, total phosphorus concentrations, and flow category for Illinois River at Chewey, Oklahoma, from 2000–2004.

[ft³/s, cubic foot per second; mg/L, milligram per liter; P, phosphorus; all water-quality and streamflow data available at *http://water.usgs.gov/ok/nwis*]

Date	Sample time	Instantaneous streamflow (ft³/s)	Total phosphorus concentrations (mg/L as P) [1]	Flow category [2]
02/16/2000	1105	231	0.17	Base flow
04/12/2000	1445	1,400	0.37	Runoff
05/07/2000	1450	3,340	0.47	Runoff
06/18/2000	1235	16,800	0.86	Runoff
06/22/2000	1215	34,700	0.96	Runoff
08/16/2000	1310	251	0.16	Base flow
09/26/2000	1330	840	0.23	Runoff
10/23/2000	1430	230	0.22	Base flow
11/07/2000	1230	1,900	0.27	Runoff
12/07/2000	1255	415	0.14	Base flow
01/30/2001	1245	4,980	0.40	Runoff
02/15/2001	1320	6,670	0.83	Runoff
02/25/2001	1010	20,600	0.46	Runoff
04/18/2001	1715	518	0.14	Base flow
05/18/2001	1635	1,220	0.24	Runoff
06/27/2001	0945	376	0.18	Runoff
08/15/2001	1300	200	0.25	Base flow
10/11/2001	1605	1,110	0.22	Runoff
12/11/2001	1210	335	0.26	Base flow
12/17/2001	1740	17,400	0.86	Runoff
02/01/2002	1345	7,420	0.53	Runoff
03/20/2002	1220	9,540	0.65	Runoff
04/08/2002	1400	11,600	0.78	Runoff
06/14/2002	1040	1,640	0.27	Runoff
08/15/2002	1210	3,230	0.44	Runoff
10/17/2002	1315	156	0.30	Base flow
12/11/2002	1000	216	0.15	Base flow
03/27/2003	1315	584	0.123	Base flow
04/23/2003	1320	293	0.144	Base flow
05/16/2003	1815	1,440	0.210	Runoff
05/17/2003	1120	5,030	0.510	Runoff
05/21/2003	1335	2,730	0.350	Runoff
06/02/2003	1520	621	0.151	Runoff
06/03/2003	1340	2,000	0.280	Runoff

Appendix 3. Instantaneous streamflows, total phosphorus concentrations, and flow category for Illinois River at Chewey, Oklahoma, from 2000–2004.—Continued

[ft^3/s, cubic foot per second; mg/L, milligram per liter; P, phosphorus; all water-quality and streamflow data available at *http://water.usgs.gov/ok/nwis*]

Date	Sample time	Instantaneous streamflow (ft^3/s)	Total phosphorus concentrations (mg/L as P) [1]	Flow category [2]
06/12/2003	1550	1,380	0.180	Runoff
07/14/2003	1610	951	0.250	Runoff
08/27/2003	1730	117	0.172	Base flow
08/30/2003	1945	286	0.183	Runoff
09/02/2003	1430	845	0.210	Runoff
10/28/2003	1530	162	0.122	Base flow
11/18/2003	1605	1,600	0.200	Runoff
12/08/2003	1415	234	0.088	Base flow
02/19/2004	1530	421	0.051	Base flow
03/04/2004	1345	5,120	0.420	Runoff
04/14/2004	1255	686	0.075	Runoff
04/23/2004	1310	9,590	0.770	Runoff
06/17/2004	1225	367	0.199	Base flow
08/18/2004	1130	379	0.109	Base flow
10/14/2004	1430	327	0.112	Base flow
11/02/2004	1000	4,780	0.430	Runoff
12/17/2004	1130	695	0.079	Base flow

[1]Year 2003 and 2004 values are reported as 3 significant digits because the precision of the analytical method changed.

[2]Base flow and runoff designated by Base-Flow Index (BFI) program (Institute of Hydrology, 1980a, 1980b).

Appendix 4. Instantaneous streamflows, total phosphorus concentrations, and flow category for Illinois River near Tahlequah, Oklahoma, from 2000-2004.

[ft³/s, cubic foot per second; mg/L, milligram per liter; P, phosphorus; <, less than the laboratory reporting level; all water-quality and streamflow data available at *http://water.usgs.gov/ok/nwis*]

Date	Sample time	Instantaneous streamflow (ft³/s)	Total phosphorus concentration (mg/L as P) [1]	Flow category [2]
02/15/2000	1700	268	0.09	Base flow
04/13/2000	0910	1,150	0.15	Runoff
05/08/2000	0920	3,010	0.28	Runoff
06/18/2000	1635	14,800	0.62	Runoff
06/22/2000	1630	33,900	0.80	Runoff
07/20/2000	1200	677	0.12	Base flow
08/29/2000	1630	189	0.09	Base flow
09/26/2000	1045	1,040	0.15	Runoff
10/19/2000	1415	251	0.11	Base flow
10/27/2000	1600	582	0.16	Runoff
11/07/2000	1400	1,540	0.19	Runoff
12/12/2000	1215	420	0.07	Base flow
01/31/2001	1040	3,840	0.21	Runoff
02/16/2001	1315	10,200	0.38	Runoff
02/25/2001	1505	25,200	0.75	Runoff
04/23/2001	1430	588	0.11	Base flow
05/19/2001	1410	2,070	0.23	Runoff
06/26/2001	1530	645	0.13	Runoff
08/16/2001	1110	312	0.10	Runoff
10/12/2001	1100	2,660	0.22	Runoff
10/24/2001	0850	368	<0.06	Runoff
11/05/2001	1250	1,690	0.35	Runoff
12/05/2001	1330	828	0.15	Runoff
12/18/2001	1210	19,500	0.54	Runoff
02/02/2002	1100	4,090	0.28	Runoff
03/21/2002	1200	7,940	0.31	Runoff
04/09/2002	1130	17,900	0.82	Runoff
06/10/2002	1300	794	0.15	Base flow
08/15/2002	1447	7,360	0.61	Runoff
10/23/2002	1145	192	0.11	Base flow
12/09/2002	1010	293	0.08	Base flow

Appendix 4. Instantaneous streamflows, total phosphorus concentrations, and flow category for Illinois River near Tahlequah, Oklahoma, from 2000-2004.—Continued

[ft³/s, cubic foot per second; mg/L, milligram per liter; P, phosphorus; <, less than the laboratory reporting level; all water-quality and streamflow data available at *http://water.usgs.gov/ok/nwis*]

Date	Sample time	Instantaneous streamflow (ft³/s)	Total phosphorus concentration (mg/L as P) [1]	Flow category [2]
02/22/2003	1000	738	0.152	Runoff
04/21/2003	1340	304	0.114	Base flow
05/16/2003	1020	2,090	0.260	Runoff
05/19/2003	1030	2,760	0.200	Runoff
05/22/2003	1030	2,480	0.230	Runoff
06/04/2003	1120	1,900	0.200	Runoff
06/10/2003	1200	512	0.108	Base flow
06/13/2003	0915	1,270	0.130	Runoff
07/15/2003	1130	886	0.157	Runoff
08/28/2003	1830	91	0.128	Base flow
08/30/2003	2200	205	0.130	Runoff
09/03/2003	1245	750	0.160	Runoff
10/28/2003	1330	180	0.087	Base flow
12/08/2003	1145	293	0.060	Base flow
02/19/2004	1130	482	0.035	Base flow
03/05/2004	0830	9,870	0.470	Runoff
04/13/2004	1400	926	0.056	Runoff
04/24/2004	1057	25,100	0.550	Runoff
06/23/2004	1050	439	0.086	Base flow
07/26/2004	1115	3,310	0.240	Runoff
08/17/2004	1100	453	0.081	Base flow
10/12/2004	1410	213	0.090	Base flow
11/02/2004	1325	9,340	0.460	Runoff
12/15/2004	1700	995	0.074	Base flow

[1]Year 2003 and 2004 values are reported as 3 significant digits because the precision of the analytical method changed.

[2]Base flow and runoff designated by Base-Flow Index (BFI) program (Institute of Hydrology, 1980a, 1980b).

Appendix 5. Instantaneous streamflows, total phosphorus concentrations, and flow category for Baron Fork at Eldon, Oklahoma, from 2000–2004.

[ft³/s, cubic foot per second; mg/L, milligram per liter; P, phosphorus; <, less than the laboratory reporting level; E, estimated value between the laboratory reporting level and the method detection limit; all water-quality and streamflow data available at *http://water.usgs.gov/ok/nwis*]

Date	Sample time	Instantaneous streamflow (ft³/s)	Total phosphorus concentration (mg/L as P) [1]	Flow category [2]
02/16/2000	0730	66	<0.05	Base flow
04/13/2000	1050	350	<0.05	Runoff
05/07/2000	1645	985	0.08	Runoff
06/17/2000	1540	7,520	1.12	Runoff
06/21/2000	1345	49,100	1.65	Runoff
06/28/2000	1630	5,350	0.98	Runoff
07/20/2000	0930	150	E0.04	Base flow
08/30/2000	1100	50	<0.05	Base flow
10/24/2000	1435	51	<0.06	Base flow
10/27/2000	1320	110	E0.04	Runoff
11/07/2000	0930	1,180	0.10	Runoff
12/20/2000	1530	192	<0.06	Runoff
01/30/2001	1015	1,270	0.13	Runoff
02/16/2001	1145	3,300	0.17	Runoff
02/25/2001	1240	4,900	0.26	Runoff
04/23/2001	1610	153	<0.06	Base flow
05/18/2001	1500	673	E0.04	Runoff
06/25/2001	1630	231	E0.04	Runoff
08/16/2001	0930	51	E0.03	Base flow
10/11/2001	1740	927	0.15	Runoff
10/23/2001	1555	136	0.13	Runoff
12/05/2001	1245	231	E0.04	Runoff
12/17/2001	1400	6,650	0.15	Runoff
02/01/2002	1045	1,700	0.15	Runoff
02/15/2002	1615	215	<0.06	Base flow
03/20/2002	1015	6,200	0.47	Runoff
04/08/2002	1607	8,030	0.49	Runoff
04/17/2002	0945	928	0.09	Runoff
06/13/2002	0845	174	E0.03	Base flow
08/14/2002	1340	4,580	0.74	Runoff
10/23/2002	1030	41	E0.04	Base flow
12/09/2002	1130	51	<0.04	Base flow

Appendix 5. Instantaneous streamflows, total phosphorus concentrations, and flow category for Baron Fork at Eldon, Oklahoma, from 2000–2004.—Continued

[ft³/s, cubic foot per second; mg/L, milligram per liter; P, phosphorus; <, less than the laboratory reporting level; E, estimated value between the laboratory reporting level and the method detection limit; all water-quality and streamflow data available at *http://water.usgs.gov/ok/nwis*]

Date	Sample time	Instantaneous streamflow (ft³/s)	Total phosphorus concentration (mg/L as P) [1]	Flow category [2]
02/22/2003	1155	258	0.023	Runoff
04/21/2003	1145	94	0.020	Base flow
05/16/2003	1200	228	0.039	Runoff
06/03/2003	1120	561	0.078	Runoff
06/10/2003	0950	133	0.025	Base flow
06/12/2003	1015	441	0.069	Runoff
07/15/2003	1310	120	0.031	Runoff
08/28/2003	0810	27	0.029	Base flow
08/30/2003	2320	61	0.031	Runoff
09/03/2003	1049	211	0.040	Runoff
10/28/2003	1245	56	0.025	Base flow
12/08/2003	1230	115	0.024	Base flow
02/19/2004	1220	202	0.016	Base flow
03/04/2004	1645	996	0.104	Runoff
03/05/2004	1415	2,370	0.310	Runoff
04/13/2004	1245	297	0.015	Base flow
04/23/2004	1035	14,900	1.080	Runoff
06/23/2004	1140	609	0.057	Runoff
08/17/2004	1230	115	0.028	Base flow
10/12/2004	1300	52	0.029	Base flow
11/02/2004	1215	1,820	0.157	Runoff
12/16/2004	0800	312	0.030	Base flow

[1]Year 2003 and 2004 values are reported as 3 significant digits because the precision of the analytical method changed.

[2]Base flow and runoff designated by Base-Flow Index (BFI) program (Institute of Hydrology, 1980a, 1980b).